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SMS/GOES CELL AND BATTERY DATA ANALYSIS

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16. Abstract

A review of the nickel-cadmium battery design developed for the Synchronous Meteorological Satellite (SMS) and Geostationary Operational Environmental Satellite (GOES) provides background and guidelines for future development, manufacture, and application of spacecraft batteries. SMS/GOES battery design, development, qualification testing, acceptance testing, and life testing/mission performance characteristics are evaluated for correlation with battery cell manufacturing process variables.

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CONTENTS

Page

CONTENTS

CONTENTS

SECTION 6

ORBITAL MISSION PERFORMANCE AND LIFE TEST

SECTION 7

CONCLUSIONS

CONTENTS

Page

APPENDIXES

ILLUSTRATIONS

ILLUSTRATIONS

TABLES

TABLES

ABSTRACT

A review of the nickel-cadmium battery design developed for the Synchronous Meteorological Satellite (SMS) and Geostationary Operational Environmental Satellite (GOES) provides background and guidelines for future development, manufacture, and application of spacecraft batteries. SMS/GOES battery design, development, qualification testing, acceptance testing, and life testing/mission performance characteristics are evaluated for correlation with battery cell manufacturing process variables.

The battery configuration employs an assembly and cell container packaging design capable of providing a measured energy density of 29 watt-hour/kg. Each battery consists of 20 series-connected 3.0 Ah prismatic cells. The battery cells are packaged in thin wall containers. The cell container wall thickness is reduced approximately 40 percent from the standard 0.63 mm, resulting in a cell package weight reduction of 6.1 percent or 7 grams. An important design feature of the battery is the T-rib four-cell unit; each group of five units is restrained by an endplate/throughbolt subassembly. Together the five units and subassembly comprise approximately 10.1 percent of the total assembly weight. Two parallel-connected batteries provide satellite load support for eclipse and non-eclipse peak load operation.

A summary of the cell development program, all manufacturing test data, battery fabrication and test data is presented. Also included are battery orbital performance data from three satellites. The batteries have performed as predicted and have provided the required energy storage function for the satellite electrical power subsystem.

SECTION 1
INTRODUCTION

PROGRAM OBJECTIVES

This report documents and summarizes specifications and processes used by Ford Aerospace & Communications Corporation (FACC) in the manufacture and test of battery cells for the SMS-A, SMS-B, and GOES-A, -B, and -C batteries. Battery cell and battery performance data obtained during vendor and FACC acceptance tests are reported. Flight battery orbital operations are investigated in an effort to correlate cell manufacturing process variables with mission performance.

BACKGROUND

Ford Aerospace & Communications Corporation's Western Development Laboratories has prepared this analysis report of the SMS/GOES battery cell and battery assembly performance in accordance with the requirements of NASA/GSFC Contract NAS5-23693. This report summarizes cell process and battery test data obtained in the performance of SMS/GOES Contracts NAS5-21575 and NAS5-20750.

Contract NAS5-21575 for the Synchronous Meteorological Satellite system was initiated on 21 December 1970. The combined phase contract was for the design, development, fabrication, testing, and delivery of one protoflight satellite (SMS-A) and two flight model satellites (SMS-B and GOES-A). SMS-A was launched on 17 May 1974 and was redesignated SMS-1. SMS-B was launched on 16 February 1975 and was redesignated SMS-2. GOES-A was launched on 16 October 1975 and was redesignated as GOES-1. GOES-B was launched on 16 June 1977 and was redesignated GOES-2. GOES-C is scheduled to be launched in 1978.

SMS/GOES satellites are part of a worldwide weather monitoring system providing the first operational geostationary environmental satellite service. A detailed description of this satellite system is contained in the final project report WDL-TR7127, dated 29 April 1977.

The battery design concepts utilized by FACC for the SMS/GOES Program emphasize weight efficient mechanical design technology which resulted in an increased energy density battery. This program represents one of the original efforts by Eagle Picher Industries, Inc., to produce reliable hermetically sealed nickel-cadmium cells for synchronous orbit satellites.

SECTION 2

DESIGN DESCRIPTION

This section describes the satellite system and power subsystem performance requirements. Battery design analyses and cell design parameters are documented and reviewed. A summary of the battery configuration in the satellite power subsystem is also presented.

SUMMARY OF SELECTED DESIGN

Power Subsystem

Major elements of the SMS/GOES electrical power subsystem are the power control unit (PCU), the solar array, and two hermetically sealed nickel-cadmium batteries. The PCU provides the electrical interface between the solar array, the batteries, and the satellite. The power subsystem is designed to support satellite loads continuously for 5 years in a geostationary synchronous orbit, while providing the following features:

- Continuous power bus regulation
- Automatic load turnoff during solar eclipse
- Excessive load disconnect
- Overload disconnect of selected loads
- Battery undervoltage protection

The major elements of the power subsystem are interconnected as shown in Figure 2-1.

Solar Array

The solar array consists of three separate solar cell array sections. The requirements of each of these sections are summarized below:

- *Main Array.* The main array design goal is to support satellite loads at the end of the 5-year orbital lifetime at summer solstice. During equinox seasons, the main array provides required battery charging power without compromising performance.
- *Battery Charge Control Arrays.* The battery charge control array is located on the cylindrical portion of the main array and is designed to charge the battery at spin angles coincident with the maximum main array power.
- *Sun Sensor Array.* This array is required to provide an output to the control electronics during satellite sunlight. It consists of two groups of solar cells located nearly diametrically opposite each other in the main array.

Battery

The batteries supply power for satellite operation during solar eclipse periods, provide power for peak current non-eclipse pulses, and provide power for electro-explosive devices which potentially exceed the solar array capability.

General requirements for the battery configuration design include compatibility with:

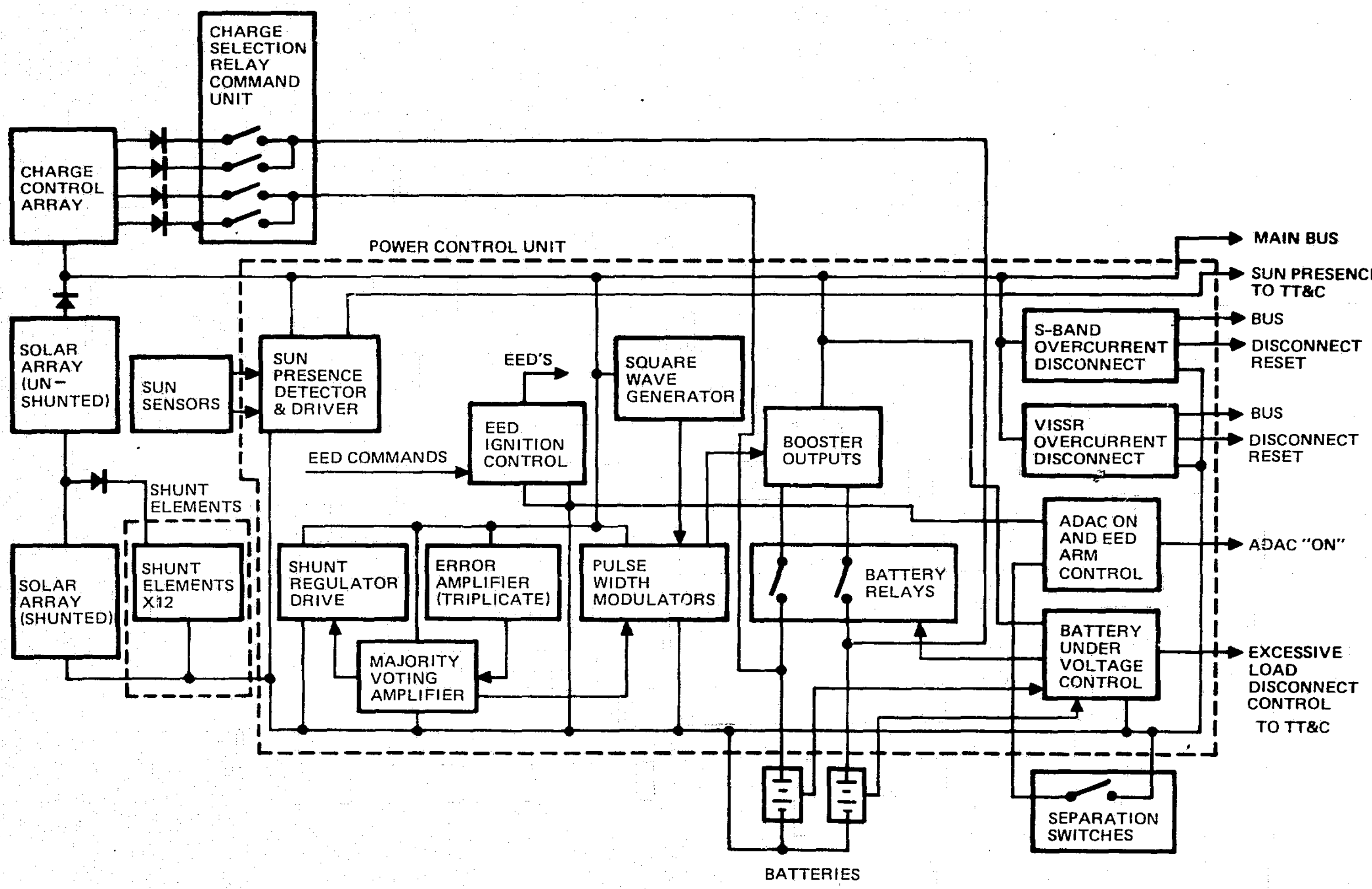

Figure 2-1. SMS/GOES Power Subsystem

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- Satellite mass properties
- Satellite thermal control
- Electrical power subsystem boost converter
- Battery charge electronics

Specific design requirements are contained in the SMS/GOES Program system specifications and include the following requirements:

- The battery configuration charge and discharge control shall have ground command provisions for each operating mode.
- The battery configuration shall provide for battery undervoltage control (cell reversal protection).
- The battery capacity must be compatible with the load requirement.

The batteries are sized at 3.0 Ah to deliver 70 watts continuous power during solar eclipse periods. These periods occur for 44 days symmetrically about each equinox season, for a total of 440 cycles over a 5-year period. Figure 2-2 shows the typical eclipse variation for each season with a maximum eclipse period of 72 minutes at equinox. The maximum battery depth of discharge at equinox is 60 percent of the rated 3.0 Ah capacity.

Battery Charge Control

Battery charging power is derived from the main solar array used in conjunction with the battery charge control arrays, which are connected in series with the array main bus. In this configuration, the battery charge arrays are operated in a current-limited mode. This provides a controlled battery charge current through individual battery charge arrays. Each array is divided into two circuits which can be connected to the battery by command. The two circuit configuration provides three charging modes: 1/3 (trickle), 2/3 (intermediate), and 3/3 (full) of the total capability.

During equinox season operation, the full charge mode produces an average charge current of 0.235 amp at beginning of life and 0.195 amp at the end of the 5-year design lifetime. Table 2-1 summarizes battery charge rates throughout the expected orbital life. If required, battery charging current can be commanded off. The battery charge rate is selected by ground command on the basis of battery charge temperature, voltage, and load support requirements. The battery is normally stored in the trickle charge mode during solstice periods if battery load sharing is not required. The battery is operated in either the intermediate or full charge mode when load sharing is required.

Battery Discharge/Undervoltage Protection

The SMS/GOES power subsystem is designed with automatic protective functions and load controls that can be overridden by ground command to the satellite. Automatic controls within the power subsystem provide undervoltage protection for each of the two batteries. Voltage is sensed across series-connected, five-cell groups. If any one cell group voltage drops below the equivalent of 1.0 volts per cell (5.0 volts for each group), the affected battery is disconnected from the main bus.

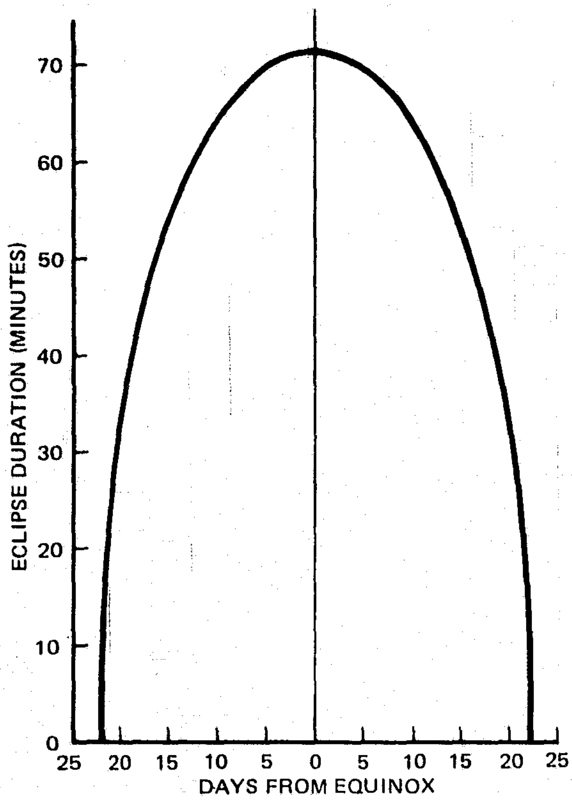

Figure 2-2. SMS/GOES Eclipse Duration at Synchronous Orbit, Including Penumbra

Table 2-1. SMS/GOES Battery Charge Current for Beginning and End of Life

SMS A & B GOES A Spacecraft	Charge Current (mA)		
Charge Mode	Trickle (1/3)	Intermediate (2/3)	Full (3/3)
BOL Equinox	85	149	235
EOL Equinox	72	126	198
BOL Summer Solstice	75	131	206
EOL Summer Solstice	63	110	174

GOES B & C Spacecraft	Charge Current (mA)		
Charge Mode	Trickle (1/3)	Intermediate (2/3)	Full (3/3)
BOL Equinox	94	161	258
EOL Equinox	81	138	222
BOL Summer Solstice	81	140	222
EOL Summer Solstice	71	121	195

BOL — Beginning of Life
EOL — End of Life (5 years)

A block diagram of the battery undervoltage/excessive load disconnect system is shown in Figure 2-3. The undervoltage sensing is accomplished by four comparator amplifiers (battery undervoltage sensor). When an undervoltage signal occurs, a time delayed signal is sent from the battery undervoltage sensor. If the excessive load disconnect does not cause removal of the battery undervoltage condition, then the battery disconnect relay is energized. The battery off command function is accomplished by grounding an input which causes the disconnect relay coil to be energized.

BATTERY DESIGN

Electrical and General Design Requirements

Each battery has 20 hermetically sealed prismatic cells connected in series, and having a rated capacity of 3.0 Ah. The battery is designed for a predicted discharge voltage range from 28 to 23 volts. Table 2-2 summarizes general battery performance requirements. Require-

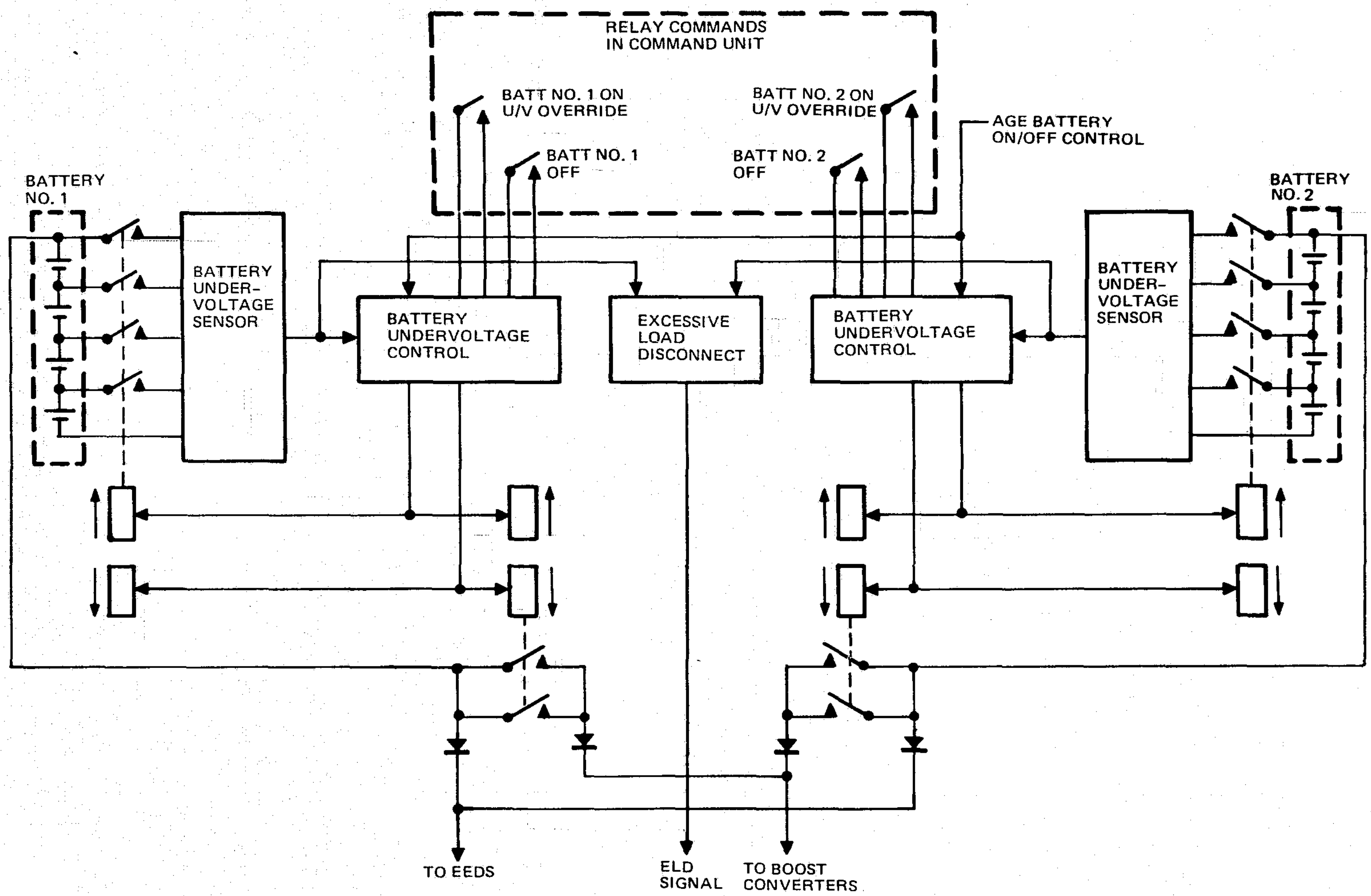

Figure 2-3. Battery Undervoltage/Control System Excessive Load Disconnect

ments listed in this table are taken from the battery assembly design specification (included in Appendix A). Each battery cell is electrically isolated from the structural assembly and the other cells with a 0.076 mm mylar film jacket. Series connection between cells is provided by three parallel-connected, Teflon-insulated 20-gage stranded copper wires, soldered to the cell terminal lugs. Battery power connections are made to the terminals at the end of the cell series string by means of redundant Teflon-insulated 20-gage stranded copper wires leading to the battery power connector. The connector is a subminiature socket, ITT Cannon Type DCM-375, which provides the battery to satellite electrical interface. The connector also provides for monitoring individual cell voltages during ground tests. The battery wiring diagram, Drawing 213828, is included in Appendix B.

Mechanical Design Requirements

Mechanical design of the battery accommodates the satellite structural interface constraints and provides mechanical restraint and thermal control. The batteries are located in adjacent quadrants on the main equipment platform of the satellite. Mounting to the equipment platform is accomplished with 12 stainless steel bolts and washers (size 6-32). A battery flatness requirement of 0.38 mm must be met prior to installation on the satellite. An electrically nonconductive zinc oxide-filled thermal grease is used to thermally couple the batteries to the equipment platform. The batteries are electrically grounded through the PCU by means of a 20 AWG lug wire as shown in View C of Drawing 213827 (included in Appendix B).

Table 2-2. SMS/GOES Battery Performance Requirements

Normal main bus battery load	35 W/battery
Battery discharge voltage range	28 to 23 V
Maximum depth of discharge	60% rated capacity
Peak discharge rate (EED device)	25 A
Maximum discharge time	1.2 hours
Minimum allowable charge time	22.8 hours
Total cycles at eclipse (5 years)	440 cycles
Cycle repetition rate	24 hours
Operating temperature	5 to 28°C
Trickle charge periods	138 days between cycling periods
Orbital lifetime	5 years minimum
Battery system	Two 20-cell assemblies
Weight/battery	3.5 kg maximum
Center of gravity	±0.92 cm
Maximum thermal load/battery	9 W

The basic component of the SMS/GOES battery is the T-rib four-cell unit restrained by an endplate/throughbolt subassembly, as illustrated in Figure 2-4. There are 5 four-cell units in each battery. The T-ribs and endplate are constructed from magnesium alloy AZ31B-H24. The material utilized for the throughbolts is 5.48 mm diameter aluminum alloy 2024-T4. The maximum dimensions of the battery are 69.9 by 143.5 by 285.8 mm. The typical battery assembly weight is 3.43 kg, including allowance for battery weight matching and center of mass adjustments required for unit interchangeability. The battery assembly and cell weight characteristics are summarized in Table 2-3.

Battery cells are immobilized in the assembly by support blocks and forces from an endplate restraining pressure of 0.66 N/mm² (96 lb/in²). The assembly is designed to survive

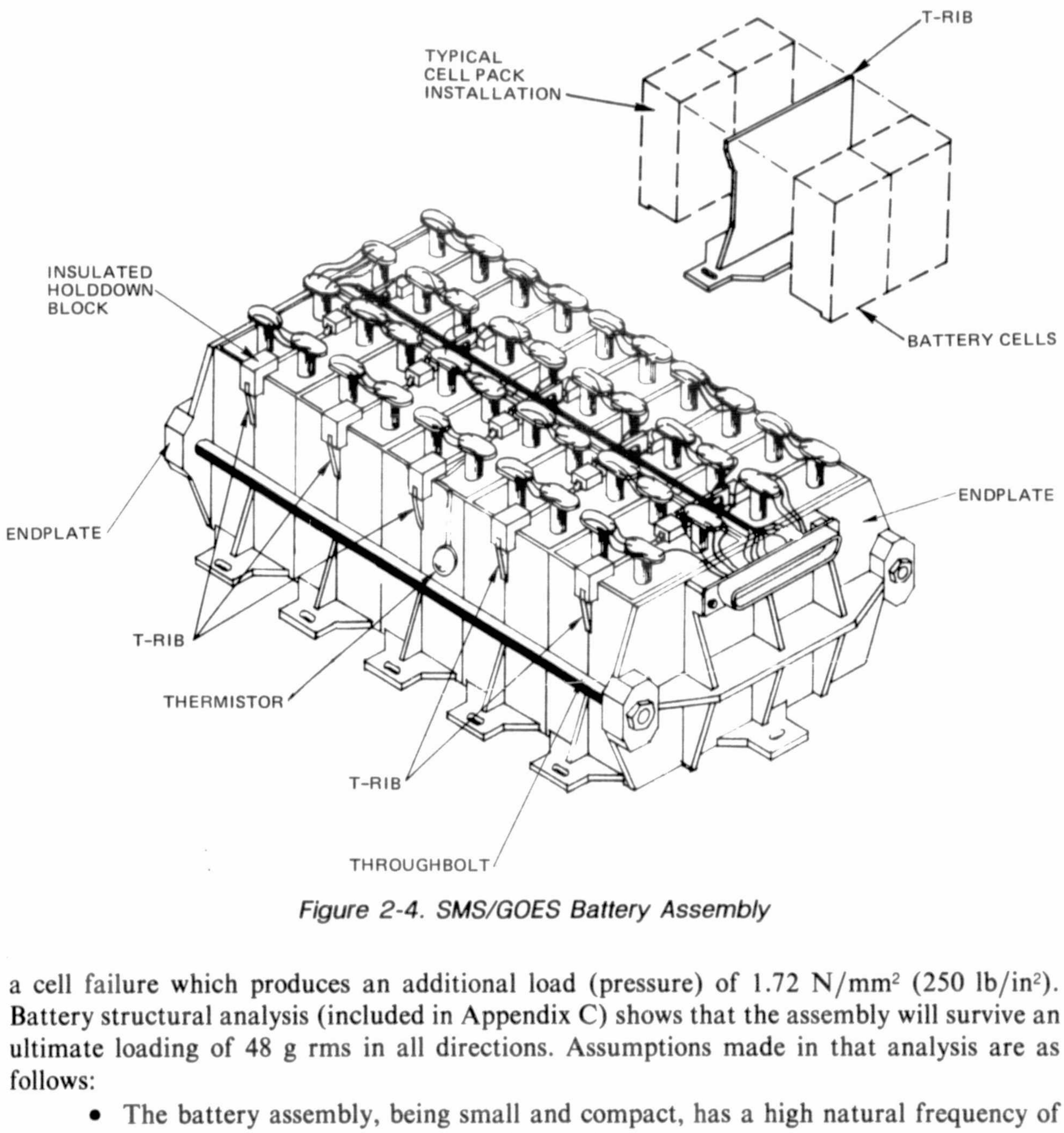

Figure 2-4. SMS/GOES Battery Assembly

a cell failure which produces an additional load (pressure) of 1.72 N/mm² (250 lb/in²). Battery structural analysis (included in Appendix C) shows that the assembly will survive an ultimate loading of 48 g rms in all directions. Assumptions made in that analysis are as follows:

- The battery assembly, being small and compact, has a high natural frequency of vibration (in the range of 100 to 300 Hz).
- Since the assembly is composed of 5 four-cell units clamped together, internal friction is high and the system exhibits moderate structural damping (on the order of 15 percent).
- In sizing the various components of the assembly, each unit of four cells is assumed to act independently, and the battery endplates support the load required to clamp the assembly together and the cell failure load (pressure) of 0.66 N/mm² (96 lb/in²).

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Table 2-4 summarizes the design stresses and factors of safety for the battery assembly. The minimum factor of safety is 1.12 for the endplate main support web in shear due to clamping and cell failure loads on the throughbolts.

Control of temperature gradients within the battery is critical to uniform cell performance because of dependence of cell charge efficiency on temperature. Passive thermal control of individual cells is accomplished by intercell thermal shunts integral with a T-rib baseplate. The T-rib provides a "heat sink" for each each group of four cells by conduction to the satellite equipment mounting platform.

Table 2-3. SMS/GOES Battery Assembly Weight Characteristics

Component	Typical Weight (grams)
Battery Cell Assembly	
Positive Electrode Assembly	41
Negative Electrode Assembly	51
KOH Electrolyte	16
Separator – Pellon 2505 ML/Holddown	5
Cover/Terminal Assembly (Dual Seals)	14
Container – Welded Sheet Stock	27
Total Per Assembly	154
Battery Assembly	
Battery Cell Assembly (20)	3080
End Plate Restrainer (2)	71
Throughbolt Assembly (2)	39
Cell T-Rib Assembly (5)	89
Holddown Blocks (15)	10
Connector/Thermistors (2)	27
Mylar, Wire, Paint, Epoxy (A/R)	110
Total Per Assembly	3426
Total for Two Assemblies	6852

Thermal Design Requirements

The design concept for temperature control of the battery consists of maintaining the battery design temperature limits within 5 to 28°C by utilizing passive thermal control techniques. The maximum temperature is controlled by selection of the effective thermal radiating area and the charge rate. The minimum temperature is determined by the thermal capacitance of the battery and coupling to the equipment platform. Figure 2-5 illustrates the battery temperature and power dissipation profile used in the battery thermal analysis (included in Appendix D) for a typical 24-hour equinox period. During post-eclipse charging, battery cell electrochemical reactions are endothermic and the minimum battery temperature is reached. As the battery receives heat from the equipment platform and enters into overcharge, a maximum temperature condition occurs.

Results of the battery thermal analysis and thermal vacuum tests show that the maximum cell temperature gradient does not exceed the 5°C design goal. A computer-aided thermal analysis was performed for three constant baseplate temperatures of 35, 20, and 5°C. Maximum battery cell temperatures for these conditions were 37, 23, and 9°C, respectively. The maximum battery cell temperature is located in the center of the assembly. This analysis was performed for magnesium alloy HM-21A cell support rib material having a thermal conductivity of 1.37 W/cm°C. Figure 2-6 summarizes thermal characteristics for this material. Due to limited availability, magnesium alloy HM-21A was replaced with AZ31B-H24 alloy material which has a thermal conductivity of 0.76 W/cm°C.

Table 2-4. SMS/GOES Battery Structural Analysis

Summary of Design Stresses and Factors of Safety				
	Ultimate		Yield	
Location	10^6 Pascals	Factor of Safety	10^6 Pascals	Factor of Safety
Cell support rib				
Web shear	6.20	23.35	4.14	20.00
Web tension	26.88	8.46	17.92	6.92
Flange shear	8.96	16.15	6.20	13.35
Flange bending	162.70	1.40	108.93	1.14
Flange bearing	24.82	13.05	16.55	12.10
End plate				
Main support web shear	129.61	1.12	37.23	2.22
Main support web bending	183.38	1.24	82.04	1.51
Side web shear	—	—	69.63	1.19
Through bolt tension	374.34	1.14	106.86	2.58
Tie-down bolt tension	13.10	17.45	8.96	13.85
Tie-down bolt shear	14.48	10.00	9.65	8.58

BATTERY CELL DESIGN

The SMS/GOES battery cell design incorporates conventional Eagle Picher manufacturing processes. Cell electrode manufacturing processes utilized in the cell design are described in the final report for GSFC Contract NAS5-21159, "Study of Process Variables Associated with Manufacturing Hermetically Sealed Nickel-Cadmium Cells," (L. Miller, Eagle Picher Industries, Inc.). Figure 2-7 shows a cross section of the RSN-3 cell assembly. The container wall thickness was reduced approximately 40 percent from the standard 0.63 mm to 0.38 mm and a yoke-type design was incorporated for the cell electrode terminal connection. The container wall thickness reduction resulted in a cell weight savings of approximately 7 grams. A weight breakdown for the cell components is included in Table 2-3. General design and construction requirements are specified in the battery cell procurement specification (included in Appendix E). These requirements specify that a 3.0 Ah rated cell deliver 3.6 Ah at 24 ± 2°C at beginning of life, and 2.4 Ah after 700 cycles at 60 percent maximum depth of discharge, based on the rated capacity.

Positive Electrode Design

Positive plate tabs are 0.127 mm thick annealed nickel strips which are welded to each plate. The positive group consists of 10 plates with tabs. The theoretical capacity of each positive plate group is approximately 5 Ah. Since the positive electrode assembly is thought

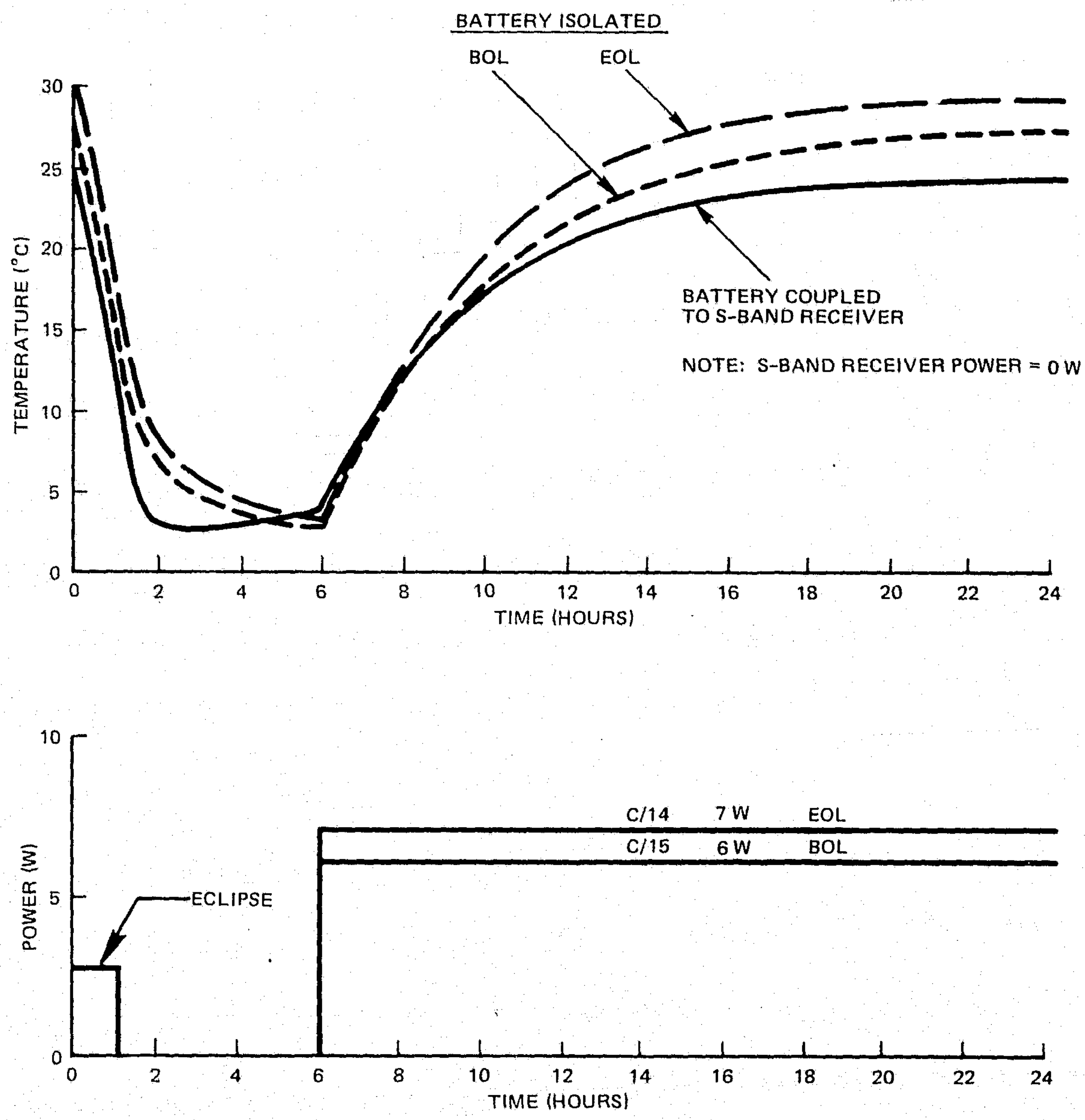

Figure 2-5. SMS/GOES Battery Temperature Profile for a Typical 24-Hour Equinox Period

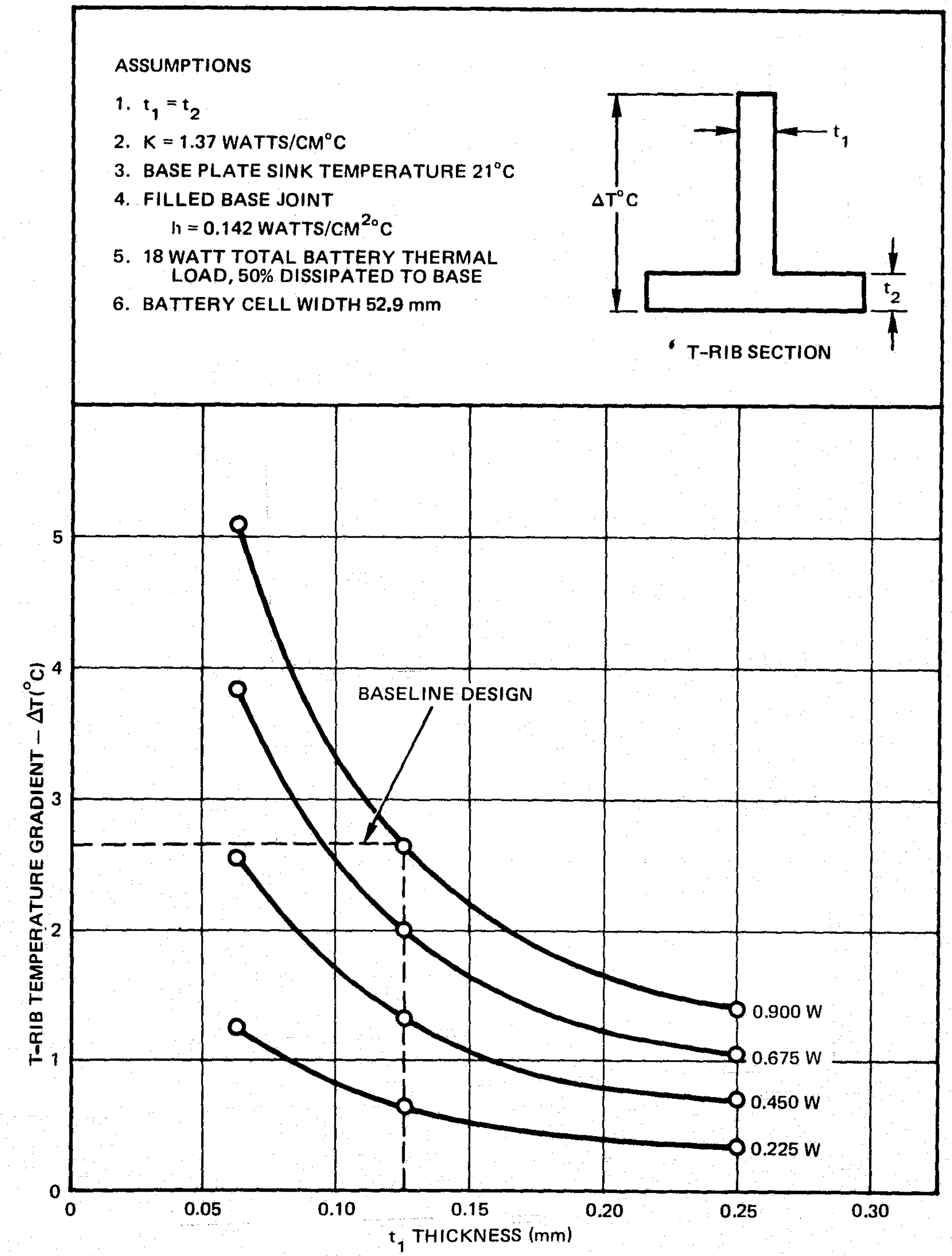

Figure 2-6. SMS/GOES Battery Assembly T-Rib Thermal Analysis

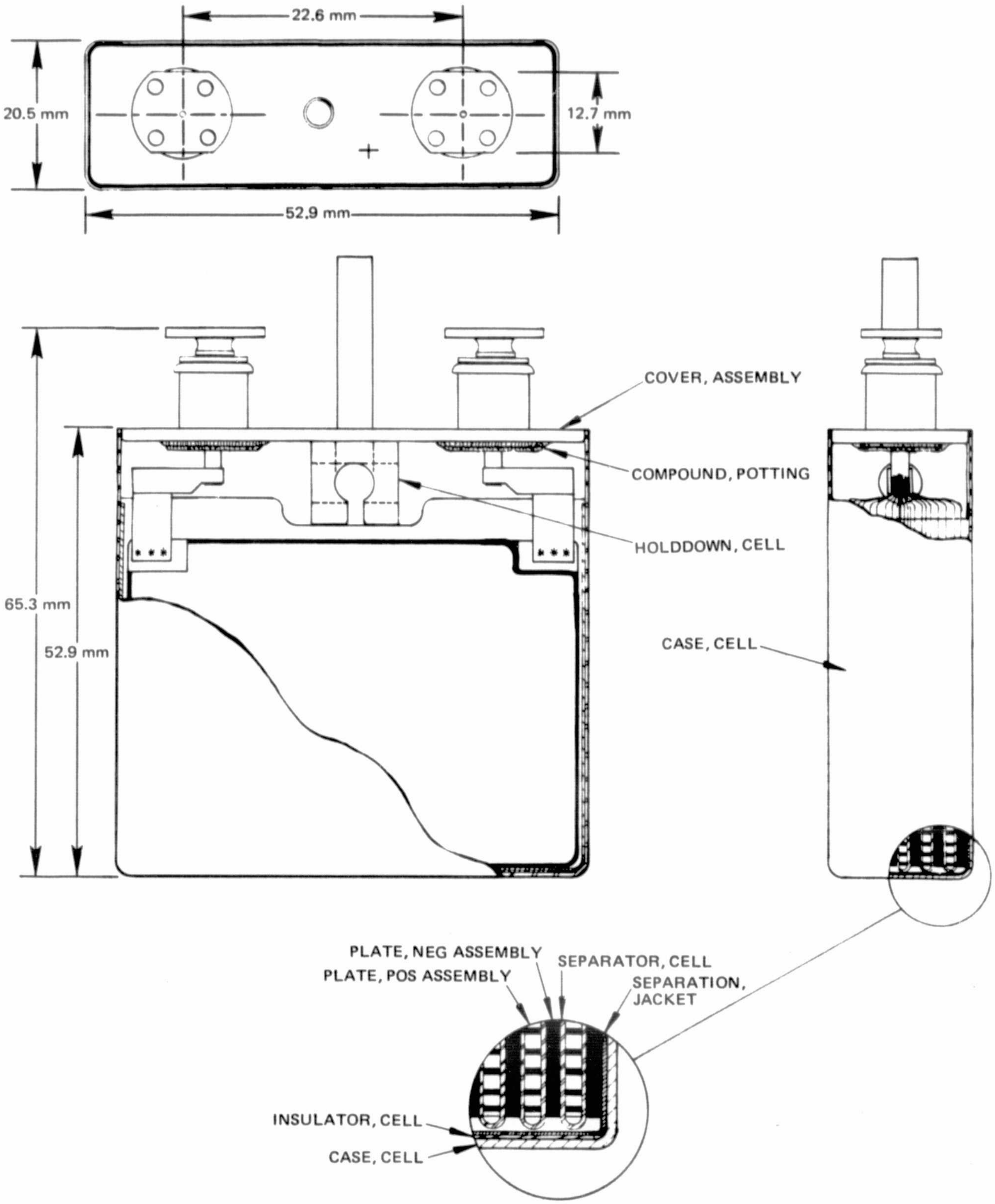

Figure 2-7. RSN-3 Cell Assembly

to have more stable electrical performance characteristics than the negative electrode assembly, the cell is designed so that the positive electrode is the limiting electrode.

Negative Electrode Design

Since the negative electrode assembly exhibits capacity degradation with cycle life, battery cells are normally manufactured with a negative-to-positive electrochemical electrode capacity ratio of 1.50:1.00 for synchronous orbit application. The negative plate group consists of 11 plates with a theoretical capacity of approximately 7.5 ampere hours. The plates are fabricated and assembled by methods similar to those described for the positive electrode assembly. The required total positive and negative electrochemical capacity characteristics are specified in Table 2-5.

Separator and Electrolyte

The separator selected for the battery cell design is made of nonwoven Pellon 2505 nylon filament material approximately 0.38 mm thick. Nylon filament material is thought to be the optimum separator material available for sealed nickel-cadmium cells operated in the temperature range of 5 to 28°C. A U-fold separator wrap configuration is used for this cell design. A 30 weight percent concentration potassium hyroxide electrolyte provides for the transport of charged ions between the electrodes. Each batch of electrolyte is analyzed for carbonate and nitrate content. Carbonate concentration must be less than 2.8 g/l and nitrate less than 1.0 mg/l.

Table 2-5. RSN-3 Cell Electrochemical Capacity Requirements

Characteristics	Electrochemical Capacity (Ratio)	
	Maximum	Minimum
Total Positive/Rated Positive	1.50	1.20
Total Negative/Total Positive	1.80	1.50
Excess Negative/Negative Precharge	2.85	2.25

Terminal Seals

The terminal seal/cover configuration selected for this cell design incorporates double ceramic alumina-to-metal seals produced by Ceramaseal, Inc. Each electrode assembly is fitted to the ceramic insulator assembly of which the body material is 96.0 ± 2.0 percent pure alumina. The insulator-to-cover junction employs a nickel 200 type stress relief configuration such that relative motion between the terminal assembly and cover applies minimum stress to the insulator and the metal-to-insulator bonds. The terminal is fitted with an oxygen and hydrogen free copper (OHFC) four-hole solder lug brazed to the cell terminal. Figure 2-8 is a cross section of the terminal seal.

Cell Container

A drawn-type container is utilized in this design. The cell container and cover are fabricated of 304L stainless steel and are joined by a continuous heliarc weld which provides a hermetic seal. Although the cell container does not directly affect performance, it does affect the weight of the battery cell. The weight of the container is primarily a function of the material thickness, and the thickness is dependent on the method of fabrication and mechanical loading requirements.

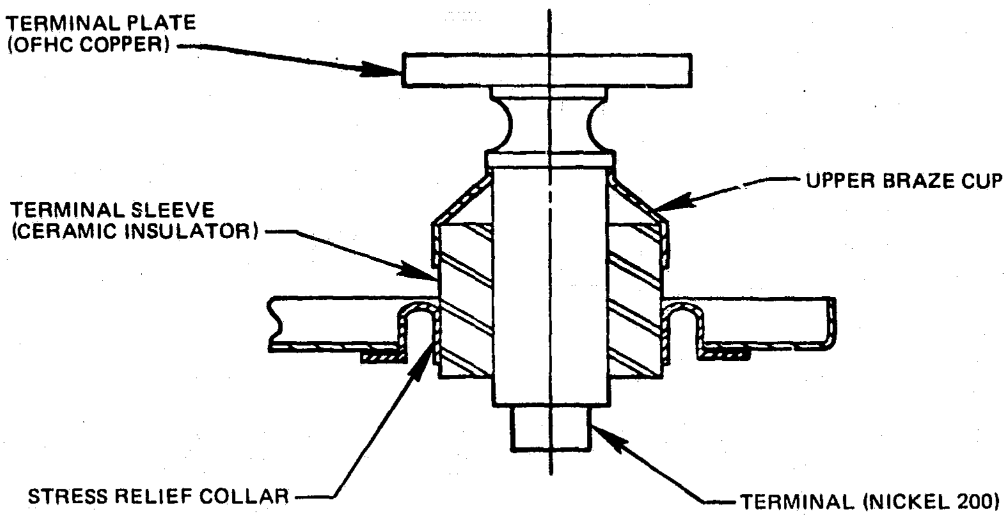

Figure 2-8. RSN-3 Cell Terminal Seal

SECTION 3

CELL DEVELOPMENT AND MANUFACTURING

VENDOR CELL DEVELOPMENT

In July 1971, a development program was initiated at Eagle Picher Industries, Inc., for the design of a sealed 3.0 Ah nickel-cadmium battery cell for synchronous orbit application. Three preproduction development cell groups were evaluated. Information from that evaluation was used in the final engineering (Lot 1) cell design. Cell production processes evolving from this development work are included in this section. Also included is a review of preproduction and engineering cell performance data and flight cell production data for Lots 3 through 8, 10, and 12.

PLATE FABRICATION PROCESS

Plaques and plates for the SMS/GOES battery cells are processed at Eagle Picher's Colorado Springs facility. Eagle Picher uses the "dry" process for manufacture of a porous nickel plaque used for both positive and negative plates. Porosity is maintained at approximately 80 and 85 percent for the positive and negative plaques, respectively, where porosity is defined as void volume based on water absorption.

Special dies for coining the sintered plaque are used to produce individual plate sizes. After coining, the plaques are immersed in a heated nitrate solution followed by cathodic polarization, rinsing, and drying. Positive plates are processed using nickel nitrate solutions and negative plates using cadmimum nitrate. Three formation cycles are performed on the processed plaques to remove excess material from the plaque surface before cutting into individual plates. These formation cycles are performed on both positive and negative plaques in a bath of potassium hydroxide.

Plate loading or active material pickup is determined by subtracting the sintered plaque weight from the impregnated plaque weight after excess active material has been removed from the plaque surface. The effective active material area on both the positive and negative plaques is 5.53 dm^2. This plaque area yields 30 plates of the RSN-3 cell size.

CELL MANUFACTURING FLOW

After receipt of plaque material from the Colorado Springs facility, final cell mechanical assembly is performed at Joplin, Mo. Basic manufacturing steps are summarized in the following paragraphs and Figure 3-1.

Positive and Negative Electrode Preparation

Positive and negative plates are die cut with radius corners to decrease chipping, flaking, and the possibility of separator mechanical breakdown between plates. After cutting, plates are weighed and the average weight determined. Plates are screened within ±3.5 percent of the average weight and edge coated with a plastic cement. The positive and negative plate tabs are then spot welded to the plates and an inspection performed for the following:

POSITIVE AND NEGATIVE ELECTRODE PREPARATION	Cut and punch plates Weigh and sort plates Edge coat plates Spot weld plate tabs Press and store plates
GROUP CONSTRUCTION	Inspect positive and negative plates Group and inspect positive plates Group and inspect negative plates
CELL ASSEMBLY PROCEDURE	Weigh positive and negative groups Degrease cell cases Preshape and spot weld tabs Trim tabs and weld terminals Install separator wrap Install cell pack in case Weld cover to case and serialize
FINAL CELL ASSEMBLY	Leak check gage assemblies and cells Record dry weight and activate cells Record wet weight and install gages Condition cycle cells Perform electrode capacity test Perform power discharge Measure negative electrode precharge
ACCEPTANCE TEST PROCEDURE	Vacuum leak check gage assemblies and cells Perform 24°C overcharge capacity test Perform 35°C capacity test Perform 0°C capacity test Perform 24°C capacity test Perform electrolyte leakage test Perform charge retention test Vacuum leak check gage assemblies and cells
FINISHED CELL PREPARATION	Pinch off and weld cell fill tubes Helium leak check cells Liquid hone cells Label cells Perform electrolyte leak check Perform final inspection

Figure 3-1. Cell Manufacturing Flow

- Active material flaking from the plate surface
- Rough edges, burrs, or snags over the entire electrode surface (inspection made with clean nylon gloves to feel for snags on fibers of gloves)
- Pimples, blisters, and peeling of sinter materials in excess of 0.051 mm above the electrode surface

Group Construction and Cell Assembly

Plates are grouped, inspected, and weighed prior to installation in the cell case. Plate tabs are preshaped and spot welded, and the plate tabs welded to the terminals on the cell case cover. Plates are separated by a U-fold separator wrap and the cell pack installed in the case. The cover is welded to the case and the cells are then serialized. Pressure gages are attached to the cell fill tubes and a leak check performed. The cell dry weight is determined and electrolyte activation is performed.

Electrode Ratio and Precharge

Cell electrode capacity ratios are determined by a starved test after electrolyte activation or fill. Electrode capacity test requirements were previously summarized in Table 2-5. Cell precharge adjustment is made following electrolyte activation and three cell conditioning cycles. Each conditioning cycle consists of a 1.5 amp charge for 4 hours minimum at room ambient conditions until a cell voltage of 1.60 volts is reached, followed by a 1.5 amp discharge to a cell voltage of 1.0 volt. Oxygen generated during overcharge is vented through a one-way relief valve set for approximately 13.79 to 27.58 x 10^{-3}N/mm^2 (2 to 4 lb/in^2).

After completion of the third conditioning charge, precharge is set by electrochemically discharging at a 0.075 amp rate (power discharging) the fully charged negative group against the cell container. Precharge specified for the SMS/GOES battery cells is 40 ± 10 percent of the excess negative electrochemical capacity measured in the starved electrode capacity test. Precharged negative capacity is determined following precharge adjustment in the same manner as for the electrode capacity test.

ACCEPTANCE TEST PROCEDURE

Following precharge adjustment, a leak check is performed on the cells and gage assemblies. The cells are given an overcharge capacity test at 24°C and capacity tests at 35, 0, and 24°C. Electrolyte leakage and open circuit cell charge retention tests are made, followed by a vacuum leak check on the cells and gage assemblies. The cells are back-filled with an oxygen/helium mixture, the gages are removed, and cell fill tubes pinched off and welded. A helium leak check is performed to verify the hermetic seal of the cell. The cells are then liquid honed and labeled, and a final electrolyte leakage test is performed. A chronological summary of the cell manufacturing and test flow is included in Appendix F.

PREPRODUCTION ENGINEERING CELL PERFORMANCE

The principal process variable evaluated in the preproduction engineering cells was electrolyte quantity. Other design parameters evaluated were:

- Cell electrical capacity

- Electrode capacity ratio
- Precharge level
- Electrode formation

Manufacturing and test data for three development cell groups are included in Tables 3-1 through 3-4. Group I cell manufacturing data summarized in Table 3-1 show relatively low negative and positive plaque loading levels compared with Groups II and III. Negative loadings of approximately 15 g/dm^2 achieved for the Group II and III cells resulted in improved starved negative capacity.

Increased positive loadings for these groups yielded improved cell capacity. In order to maintain minimum specified negative-to-positive cell electrode ratios in subsequent production lots, positive loadings were reduced to a range of 11.6 to 13.3 g/dm^2. Additional discussion of development work for electrolyte optimization is included in the following paragraphs.

Group I Development Cells

Eleven cells were fabricated in the first development group. A 30 weight percent concentration potassium hydroxide electrolyte was evaluated for quantities corresponding to 18, 19, and 20 percent of the cell core weight (or 11.4 to 14.0 cc KOH). Following three conditioning cycles and precharge adjustment, the Group I cells were electrically tested. Data summarized in Table 3-2 show a trend of higher cell overcharge pressures with increased electrolyte fill. The cells were tested initially at 24, 40, 0, and 24°C, followed by a 10-cycle synchronous orbit test simulation at 30°C. Because this cell group delivered a lower positive electrode capacity than desired, a decision was made to fabricate a second cell group with increased positive plate loadings.

Group II Development Cells

Twelve cells were evaluated in the second development group. The first six cells were subjected to three standard conditioning cycles after electrolyte activation. Plates for the second six cells were first given a special flooded electrolyte three formation cycle treatment. These six cells were then assembled and subjected to three standard conditioning cycles prior to precharge adjustment. Group II cell electrolyte fill quantities were 17, 18, and 19 percent of the cell core weight (or 12.6 to 14.0 cc KOH). Data summarized in Table 3-1 show that increased plate loadings and capacity values were achieved for this group. No significant improvement in the cell negative-to-positive electrode ratio resulted from the increased loadings. The six cells in this group containing plates subjected to the special formation cycles had lower charging pressures and voltages, as summarized in Table 3-3. Cells were initially tested at 24, 40, 0, and 24°C, followed by a 23-cycle synchronous orbit test simulation at temperatures ranging from 5 to 30°C. During this test, all Group II cells exhibited some discharge voltage fading that was believed due to inadequate negative electrode precharge.

Group III Development Cells

Twelve cells were evaluated in the third development group. Plaque material for the Group III cells was subjected to an extra three high rate flooded electrolyte formation cycles at the Colorado Springs facility to improve active material electrochemical utilization. The plaque

material was then shipped to the Joplin facility for plate processing and cell fabrication. Electrolyte fill remained at 17, 18, and 19 percent of core weight (or 12.6 to 14.0 cc KOH). Data summarized in Table 3-1 show that increased plate loadings were achieved for this group; however, some undesirable positive plaque growth and associated plate surface cracking was observed. Following three conditioning cycles and precharge adjustment, the Group III cells were electrically tested. These cells exhibited lower pressure characteristics than cells from Groups I and II not having the special formation cycling. The Group III cells were tested initially at 24, 40, 0, and 24°C, followed by a 12-cycle synchronous orbit test simulation at 30°C. Cells having lower electrolyte levels exhibited reduced pressure characteristics, as summarized in Table 3-4. Except for some marginal charge retention test results, performance for this cell group was generally acceptable at conclusion of the tests.

Table 3-1. Development Cell Manufacturing Data

	Group I	Group II	Group III
Negative loading (g/dm^2)	12.0	14.6	15.5
Negative group weight (g)	44.4	52.4	50.6
Negative group thickness (mm)	7.9	8.9	8.5
Positive loading (g/dm^2)	11.6	13.3	14.3
Positive group weight (g)	39.5	43.1	42.4
Positive group thickness (mm)	6.6	7.2	7.0
Core thickness (mm)	18.2	20.0	18.2
Electrolyte fill (cc)	(a)	(a)	(a)
Cell dry weight (g)	155.0	163.2	140.4
Starved negative capacity (Ah)	5.31	6.37	6.20
Starved positive capacity (Ah)	4.04	4.80	4.90
Negative power discharge (Ah)	1.20	1.20	1.20
Measured negative precharge (Ah)	1.08 (0.07)[b]	0.63 (0.37)[b]	0.70 (0.10)[b]
Negative to positive ratio	1.31	1.33	1.27
Discharged excess negative (Ah) (electro-chemically available)[c]	0.19	0.94	0.60

(a) See Tables 3-2, 3-3 and 3-4 for specific electrolyte quantities evaluated for these cell groups

(b) Starved negative capacity — starved positive capacity — negative power discharge = calculated negative precharge (Ah)

(c) Starved negative capacity — starved positive capacity — measured precharge = discharged excess negative

Development Cell Test Results Summary

Results of the three development cell group experiments indicate that several significant process and design parameter values tend to improve the cell performance. Information from these experiments was utilized on the flight cell production. These improvements are summarized as follows.

- The positive plate active material loading range should be controlled to attain the desired positive plate capacity and required minimum negativeto-positive capacity ratio. Loading values in the range of 11.6 to 13.3 g/dm^2 appear to be satisfactory based upon subsequent production cell performance.
- High rate charge/discharge cycling of positive and negative plaques after active material impregnation appears to enhance active material utilization in the cell, as exhibited in the cell 0°C overcharge voltage test with values of 1.48 volts/cell maximum and low cell internal oxygen

Table 3-2. Group I Cell Development Test Data

	18%		19%		20%							Requirement	
Electrolyte Fill (cc)	11.9	11.4	12.6	12.6	13.1	13.0	12.9	13.6	13.7	13.8	14.0		
Cell S/N	6	7	3	4	1	2	5	8	9	10	11		
C/2 Conditioning Cycle 2 Capacity (Ah)	3.85	3.80	4.02	3.92	3.97	3.85	3.87	4.07	4.02	4.17	3.85	N/A	N/A
24°C C/10 Charge for 40 hours													
Peak Voltage (V)	(ECT)	1.41	1.42	1.42	1.42	(ECT)	1.42	1.41	1.41	1.42			
Peak Pressure $10^{-3}N/mm^2$		0	200	97	207		317	407	241	317	(ECT)	517	max
($lb/in.^2$)		(0)	(29)	(14)	(30)		(46)	(59)	(35)	(46)		(75)	
C/2 Capacity (Ah)		3.70	3.83	3.75	3.85		4.03	3.90	4.00	4.08		3.60	min
Charge Retention (V)		1.20	1.07	1.06	1.08		1.20	1.06	1.19	1.08		1.16	min
24°C C/10 Charge for 20 hours													
Peak Voltage (V)		1.460	1.450	1.456	1.458		1.467	1.460	1.450	1.462		1.46	max
Peak Pressure $10^{-3}N/mm^2$		0	117	68.9	82.7		89.6	200	68.9	138		517	max
($lb/in.^2$)		(0)	(17)	(10)	(12)		(13)	(29)	(10)	(20)		(75)	
C/2 Capacity (Ah)		3.50	3.37	3.37	3.65		4.03	3.45	4.00	3.60		3.60	min
24°C C/10 Charge for 20 hours													
Peak Voltage (V)		1.450	1.439	1.145	1.449		1.460	1.448	1.440	1.450		1.46	max
(Retest) Peak Pressure $10^{-3}N/mm^2$		0	159	131	103		138	243	48.3	152		517	max
($lb/in.^2$)		(0)	(23)	(19)	(15)		(20)	(34)	(7)	(22)		(75)	
C/2 Capacity (Ah)		3.53	3.37	3.45	3.70		3.90	3.55	3.88	3.70		3.60	min
40°C C/10 Charge for 20 hours													
Peak Voltage (V)		1.38	1.38	1.38	1.38		1.37	1.38	1.37	1.38		1.39	max
Peak Pressure $10^{-3}N/mm^2$		200	607	607	655		689	689	469	689		517	max
($lb/in.^2$)		(29)	(88)	(88)	(95)		(100)	(100)	(68)	(100)		(75)	
C/2 Capacity (Ah)		2.12	2.60	2.43*	2.35*		2.80*	2.58*	2.65	2.67*		2.00	min
0°C C/20 Charge for 48 hours													
Peak Voltage (V)		1.530	1.553	1.550	1.550		1.628	1.554	1.628	1.566		1.52	max
Peak Pressure $10^{-3}N/mm^2$		0	393	200	172		689	483	138	483		517	max
($lb/in.^2$)		(0)	(57)	(29)	(25)		(100)	(70)	(20)	(70)		(75)	
C/2 Capacity (Ah)		2.80	2.98	3.12	3.73		3.98	3.33	3.73	3.55		3.00	min
24°C C/10 Charge for 20 hours													
Peak Voltage (V)		1.431	1.438	1.429	1.426		1.420	1.434	Shorted	1.434		1.46	max
Peak Pressure $10^{-3}N/mm^2$		0	503	372	510		34.5	662		621		517	max
($lb/in.^2$)		(0)	(73)	(54)	(50)		(5)	(96)		(90)		(75)	
C/2 Capacity (Ah)		3.22	3.40	3.45	3.55		Reversed	3.48		3.68		3.60	min
Charge Retention Voltage (V)		1.230	1.210	1.223	1.225			1.218		1.223		1.16	min
Synchronous Orbit Cycle Test (DVTP-159)													
Cycle 1 C/10 Charge for 22.8 hours													
Peak Voltage (V)		1.400	1.400	1.397	1.392			1.398		1.400		1.43	max
(30°C) Peak Pressure $10^{-3}N/mm^2$		172	641	510	517			689		689		517	max
($lb/in.^2$)		(25)	(93)	(74)	(75)			(100)		(100)		(75)	
C/2 72 Minute Voltage (V)		1.186	1.219	1.203	1.208			1.219		1.224		1.16	min
Cycle 2 C/10 Charge for 22.8 hours													
Peak Voltage (V)		1.396	1.394	1.390	1.386			1.392		1.396		1.43	max
(30°C) Peak Pressure $10^{-3}N/mm^2$		345	689	689	689			689		689		517	max
($lb/in.^2$)		(50)	(100)	(100)	(100)			(100)		(100)		(75)	
C/2 72 Minute Voltage (V)		1.153	**	**	**			**					
Cycle 10 C/10 Charge for 22.8 hours													
Peak Voltage (V)		1.390										1.43	max
(30°C) Peak Pressure $10^{-3}N/mm^2$		503										517	max
($lb/in.^2$)		(73)										(75)	
C/2 72 Minute Voltage (V)		1.110										1.16	min
Starved Positive ECT (Ah)	4.12	4.12				3.88					4.12		
Starved Negative ECT (Ah)	5.20	5.15				4.83					5.90		
Flooded Positive ECT (Ah)						4.12					4.12		
Flooded Negative ECT (Ah)						5.78					6.45		

*Vented to atmospheric pressure prior to 0°C test.
**Removed from test due to high pressure

(ECT – Electrode Capacity Test)

Table 3-3. Group II Cell Development Test Data

	17%				18%				19%				
Electrolyte Fill (cc)	12.6	12.6	12.6	12.6	13.3	13.3	13.3	13.3	14.0	14.0	14.0	14.0	
Cell S/N	12	14	18*	21*	13	17	22*	23*	15	16	19*	20*	Requirement
C/2 Conditioning Cycle 2 Capacity (Ah)	4.82	4.80	4.80	4.83	4.72	4.90	4.85	4.93	4.97	4.97	4.85	4.90	N/A
24°C C/10 Charge for 20 hours													
Peak Voltage (V)	1.45	1.46	1.43	1.42	1.45	1.46	1.42	1.42	1.46	1.46	1.43	1.42	1.46 max
Peak Pressure $10^{-3}N/mm^2$	200	117	0	0	145	248	41.4	0	193	241	74.8	68.9	517 max
($lb/in.^2$)	(29)	(17)	(0)	(0)	(21)	(36)	(6)	(0)	(28)	(35)	(11)	(10)	(75)
C/2 Capacity (Ah)	4.45	4.45	4.45	4.45	4.38	4.55	4.55	4.44	4.63	4.63	4.50	4.65	3.60 min
40°C C/10 Charge for 20 hours													
Peak Voltage (V)	1.38	1.38	1.36	1.36	1.38	1.38	1.36	1.36	1.38	1.38	1.36	1.36	1.39 max
Peak Pressure $10^{-3}N/mm^2$	372	228	75.8	55.1	276	421	286	234	434	490	379	496	517 max
($lb/in.^2$)	(54)	(33)	(11)	(8)	(40)	(61)	(56)	(34)	(63)	(71)	(55)	(72)	(75)
C/2 Capacity (Ah)	2.88	2.85	2.70	2.72	2.83	2.93	2.70	2.70	2.93	3.08	2.68	2.68	2.00 min
0°C C/20 Charge for 48 hours													
Peak Voltage (V)	1.54	1.54	1.50	1.54	1.54	1.49	1.56	1.60	1.60	1.60	1.60	1.58	1.52 max
Peak Pressure $10^{-3}N/mm^2$	152	241	0	0	159	276	89.6	117	276	324	448	228	517 max
($lb/in.^2$)	(22)	(35)	(0)	(0)	(23)	(40)	(13)	(17)	(40)	(47)	(65)	(33)	(75)
C/2 Capacity (Ah)	4.15	4.25	4.33	4.30	4.25	4.15	4.45	4.67	4.28	4.40	4.73	4.73	3.00 min
24°C C/10 Charge for 48 hours													
Peak Voltage (V)	1.44	1.44	1.39	1.39	1.44	1.44	1.39	1.40	1.44	1.44	1.40	(ECT)	1.46 max
Peak Pressure $10^{-3}N/mm^2$	462	372	0	0	469	579	96.5	103	552	683	421		517 max
($lb/in.^2$)	(67)	(54)	(0)	(0)	(68)	(84)	(14)	(15)	(80)	(99)	(61)		(75)
C/2 Capacity (Ah)	4.32	4.23	4.27	4.30	4.23	4.38	4.40	4.35	4.48	4.11	4.40		3.60 min
Synchronous Orbit Cycle Test (DVTP-159)													
30°C Cycle 1 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.40	1.40	1.38	1.38	1.40	1.40	1.38	1.38	1.41	(ECT)	1.38		1.43 max
Peak Pressure $10^{-3}N/mm^2$	586	496	634	179	552	621	317	607	634		593		517 max
($lb/in.^2$)	(85)	(72)	(92)	(26)	(80)	(90)	(46)	(88)	(92)		(86)		(75)
C/2 72 Minute Voltage (V)	1.23	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.23		1.22		1.16 min
30°C Cycle 2 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.42	1.42	1.38	1.38	1.42	1.42	1.38	1.38	1.42		1.39		1.43 max
Peak Pressure $10^{-3}N/mm^2$	503	469	303	207	552	572	386	641	565		648		517 max
($lb/in.^2$)	(73)	(68)	(44)	(30)	(80)	(83)	(56)	(93)	(82)		(94)		(75)
C/2 72 Minute Voltage (V)	1.24	1.22	1.22	1.22	1.21	1.22	1.22	1.23	1.22		1.21		1.16 min
30°C Cycle 7 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.40***	1.40	1.38	1.38	1.40***	(ECT)	1.38	(ECT)	(ECT)		(ECT)		1.43 max
Peak Pressure $10^{-3}N/mm^2$	689	621	207	138	689			276					517 max
($lb/in.^2$)	(100)	(90)	(30)	(20)	(100)			(40)					(75)
C/2 72 Minute Voltage (V)	1.20	1.19	1.18	1.15	1.18		1.17						1.16 min
20°C Cycle 10 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.46	1.48	1.43	1.44	1.47		1.44						1.47 max**
Peak Pressure $10^{-3}N/mm^2$	97	48.2	0	0	55.1		0						517 max
($lb/in.^2$)	(14)	(7)	(0)	(0)	(8)		(0)						(75)
C/2 72 Minute Voltage (V)	1.23	1.22	1.24	1.24	1.23		1.25						1.16 min

Table 3-3. Group II Cell Development Test Data (Continued)

	17%				18%				19%				
Electrolyte Fill (cc)	12.6	12.6	12.6	12.6	13.3	13.3	13.3	13.3	14.0	14.0	14.0	14.0	
Cell S/N	12	14	18*	21*	13	17	22*	23*	15	16	19*	20*	Requirement
20°C Cycle 16 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.46	1.43	1.41	1.42	1.44		1.42						1.47 max
Peak Pressure $10^{-3}N/mm^2$	400	359	103	55.1	386		89.6						517 max
(lb/in.^{2})	(58)	(52)	(15)	(8)	(56)		(13)						(75)
C/2 72 Minute Voltage (V)	1.13	1.21	1.22	1.20	1.21		1.22						1.16 min
5°C Cycle 17 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.60	1.62	1.54	1.62	1.61		1.63						1.51 max
Peak Pressure $10^{-3}N/mm^2$	586	607	34.5	207	55.1		414						517 max
(lb/in.^{2})	(85)	(88)	(5)	(30)	(8)		(60)						(75)
C/2 72 Minute Voltage (V)	1.23	1.23	1.24	1.24	1.23		1.24						1.16 min
5°C Cycle 18 C/10 Charge for 22.8 hours													
Peak Voltage (V)	***	***	1.53	1.60	1.57		***						1.51 max
Peak Pressure $10^{-3}N/mm^2$	689	689	34.5	358	552		689						517 max
(lb/in.^{2})	(100)	(100)	(5)	(78)	(80)		(100)						(75)
C/2 72 Minute Voltage (V)	1.22	1.21	1.23	1.23	1.22		1.24						1.16 min
5°C Cycle 19 C/10 Charge for 22.8 hours													
Peak Voltage (V)			1.53	1.57	1.54								1.51 max
Peak Pressure $10^{-3}N/mm^2$			34.5	552	531								517 max
(lb/in.^{2})			(5)	(80)	(77)								(75)
C/2 72 Minute Voltage (V)			1.21	1.21	1.20								1.16 min
Cycle 20 C/10 Charge for 22.8 hours													
Peak Pressure $10^{-3}N/mm^2$	552	621	34.5	496	386		689						517 max
(lb/in.^{2})	(80)	(90)	(5)	(72)	(56)		(100)						(75)
5 Day Recombination Pressure													
$10^{-3}N/mm^2$	228	186	0	124	138		179						
(lb/in.^{2})	(33)	(27)	(0)	(18)	(20)		(26)						
5°C Cycle 21 C/15 Charge for 22.8 hours													
Peak Voltage (V)	1.48	1.49	1.45	1.56	1.51		1.50						1.51 max
Peak Pressure $10^{-3}N/mm^2$	152	117	0	20.6	110		0						517 max
(lb/in.^{2})	(22)	(17)	(0)	(3)	(16)		(0)						(75)
C/2 72 Minute Voltage (V)	1.21	1.21	1.20	1.20	1.21		1.19						1.16 min
5°C Cycle 22 C/15 Charge for 22.8 hours													
Peak Voltage (V)	1.49	1.49	1.48	1.56	1.48		1.54						1.51 max
Peak Pressure $10^{-3}N/mm^2$	124	68.9	0	68.9	82.7		0						517 max
(lb/in.^{2})	(18)	(10)	(0)	(10)	(12)		(0)						(75)
C/2 72 Minute Voltage (V)	1.20	1.18	1.20	1.18	1.19		1.18						1.16 min
10°C Cycle 23 C/15 Charge for 22.8 hours													
Peak Voltage (V)	1.47	1.48	1.44	1.47	1.47		1.47						1.51 max
Peak Pressure $10^{-3}N/mm^2$	138	89.6	0	68.9	82.7		0						517 max
(lb/in.^{2})	(20)	(13)	(0)	(10)	(12)		(0)						(75)
C/2 72 Minute Voltage (V)	1.20	1.19	1.20	1.17	1.19		1.19						1.16 min
Starved Positive ECT (Ah)									4.75	4.95	4.60	4.88	
Starved Negative ECT (Ah)									6.28	6.45	6.28	6.45	
Flooded Positive ECT (Ah)						5.15		5.09	5.38	5.07	5.15	4.78	
Flooded Negative ECT (Ah)						shorted		6.46	6.58	7.25	6.35	6.28	

*Plates For These Cells Subjected To A Special Flooded Electrolyte Three Formation Cycle Treatment

**Cells Reconditioned During Cycles 8 and 9

***Cells Removed From Charge Due To Excessive Pressure

(ECT — Electrode Capacity Test)

Table 3-4. Group III Cell Development Test Data

	17%				18%				19%				
Electrolyte Fill (cc)	12.6	12.6	12.6	12.6	13.3	13.3	13.3	13.3	14.0	14.0	14.0	14.0	
Cell S/N	31	32	33	34	35	36	37	38	39	40	41	42	Requirement
Conditioning Cycle 2 Capacity (Ah)	4.65	4.67	4.67	4.55	4.55	4.67	4.67	4.67	4.70	4.72	4.75	4.72	N/A
24°C C/10 Charge for 20 hours													
Peak Voltage (V)	1.417	1.414	1.415	1.420	1.420	1.420	1.420	1.418	1.405	1.420	1.420	1.424	1.46 max
Peak Pressure 10^{-3}N/mm^2	0	0	0	0	0	0	0	0	0	0	0	0	517 max
(lb/in.^{2})	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(75)
C/2 Capacity (Ah)	4.58	4.60	4.60	4.63	4.68	4.68	4.68	4.58	4.10	4.70	4.72	4.72	3.60 min
40°C C/10 Charge for 20 hours													
Peak Voltage (V)	1.370	1.370	1.369	1.370	1.370	1.370	1.369	1.366	1.365	1.368	1.369	1.370	1.39 max
Peak Pressure 10^{-3}N/mm^2	0	0	0	0	0	6.89	13.8	13.8	34.5	20.7	20.7	55.2	517 max
(lb/in.^{2})	(0)	(0)	(0)	(0)	(0)	(1)	(2)	(2)	(5)	(3)	(3)	(8)	(75)
C/2 Capacity (Ah)	2.85	2.88	2.85	2.88	2.97	2.95	2.95	2.90	2.58	2.98	3.00	3.03	2.00 min
0°C C/20 Charge for 48 hours													
Peak Voltage (V)	1.480	1.480	1.477	1.480	1.480	1.480	1.480	1.478	1.426	1.480	1.480	1.488	1.52 max
Peak Pressure 10^{-3}N/mm^2	0	0	0	0	6.89	13.8	20.7	20.7	0	20.7	41.4	55.2	517 max
(lb/in.^{2})	(0)	(0)	(0)	(0)	(1)	(2)	(3)	(3)	(0)	(3)	(6)	(8)	(75)
C/2 Capacity (Ah)	4.37	4.37	4.23	4.33	4.47	4.42	4.42	4.37	3.10	4.53	4.50	4.40	3.00 min
24°C C/10 Charge for 48 hours													
Peak Voltage (V)	1.426	1.427	1.418	1.424	1.425	1.425	1.425	1.416	1.410	1.417	1.419	1.424	1.46 max
Peak Pressure 10^{-3}N/mm^2	20.7	20.7	13.8	13.8	41.4	55.2	62.1	75.8	193	96.5	131	131	517 max
(lb/in.^{2})	(3)	(3)	(2)	(2)	(6)	(8)	(9)	(11)	(28)	(14)	(19)	(19)	(75)
C/2 Capacity (Ah)	4.58	4.58	4.43	4.52	4.68	4.50	4.58	4.45	4.00	4.60	4.63	4.60	3.60 min
Synchronous Orbit Cycle Test (DVTP-159)													
30°C Cycle 1 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.398	1.397	1.393	1.396	1.396	1.394	1.393	1.389	1.386	1.390	1.393	1.395	1.143 max
Peak Pressure 10^{-3}N/mm^2	117	68.9	117	55.2	165	186	207	221	365	317	331	317	517 max
(lb/in.^{2})	(17)	(10)	(17)	(8)	(24)	(27)	(30)	(32)	(53)	(46)	(48)	(46)	(75)
C/2 72 Minute Voltage (V)	1.243	1.240	1.236	1.240	1.246	1.240	1.245	1.239	1.234	1.245	1.248	1.249	1.16 min
30°C Cycle 12 C/10 Charge for 22.8 hours													
Peak Voltage (V)	1.396	1.395	1.393	1.394	1.393	1.390	1.390	1.390	1.395	1.390	1.390	1.393	1.43 max
Peak Pressure 10^{-3}N/mm^2	124	62.1	117	89.6	172	324	276	296	455	310	427	517	517 max
(lb/in.^{2})	(18)	(9)	(17)	(13)	(25)	(47)	(40)	(43)	(66)	(45)	(62)	(75)	(75)
C/2 72 Minute Voltage (V)	1.180	1.175	1.179	1.178	1.180	1.18	1.185	1.179	1.109	1.186	1.188	1.194	1.16 min
C/2 Capacity (Ah)	3.35	3.28	3.33	3.28	3.35	3.35	3.25	3.10	2.48	3.33	3.40	3.58	N/A
Charge Retention Voltage (V)	1.16	1.16	1.17	1.15	1.15	1.12	1.13	1.15	0.77	1.13	1.11	1.08	1.16 min
Starved Positive ECT (Ah)	4.90	4.65		4.65	4.90			4.48					
Starved Negative ECT (Ah)	6.20	5.30		5.32	6.20			4.85					
Flooded Positive ECT (Ah)		4.57		4.57		4.75		4.45				4.78	
Flooded Negative ECT (Ah)		5.77		5.77		5.91		5.65		5.91		5.96	

(ECT — Electrode Capacity Test)

gas pressure values, typically 20.68 x 10^{-3}N/mm^2 (3 lb/in^2).

- Electrolyte fill volumes of 12.6 to 13.3 cc of 30 percent by weight KOH (17 to 18 percent of the cell core weight) provides satisfactory cell gas pressure characteristics during overcharge conditions.
- After low rate power discharge (C/50 to C/100) of the negative electrode during the precharge adjustment, the amount of precharge measured is usually greater than that calculated as shown in Table 3-1.

SELECTED ENGINEERING CELL DESIGN

Lot 1 cell production for the engineering and qualification batteries was initiated upon completion of the cell development group tests. A cell negative-to-positive electrode capacity ratio of 1.46:1.00 was obtained by reducing the positive and negative plate loadings to approximately 12.8 and 14.3 g/dm^2, respectively. Data from the engineering cell manufacturing and test operations are summarized in Tables 3-5 and 3-6. Cell pressure characteristics summarized in Table 3-6 are representative of an electrolyte fill of 18.7 percent of the cell core weight (or 12.9 cc KOH). Increased negative-to-positive cell capacity ratios that were achieved for this lot provided the margin for the relatively higher levels of precharge and discharged excess negative capacities obtained. The cells showed no significant reduction in performance during testing at 24, 35, 0, and 24°C. The maximum cell overcharge voltage at 0°C was 1.515 volts, typical, compared with the specified limit of 1.52 volts.

FLIGHT CELL PRODUCTION

Flight cell production was initiated based on results of development and engineering cell tests. Cell production data for Lots 1, 3 through 8, 10, and 12 (summarized in Table 3-7) compare relative differences in these lots. Cell electrolyte fill was generally maintained at 18.0 percent of the cell core weight except for Lots 3 and 4 where the fill values were 22.1 and 19.7 percent, respectively. Cells from those lots were rejected for flight use because of cell case and cover assembly distortion due to high pressure characteristics associated with increased electrolyte filling. Average positive and negative plate loadings for the flight lots were 12.3 and 14.5 g/dm^2, respectively. Negative active material loading ranged from 13.3 to 15.0 g/dm^2, except for the Lot 8 cells which had negative loadings of 16.0 g/dm^2. Positive loadings ranged from 11.3 to 12.8 g/dm^2. Starved negative-to-positive electrochemical capacity tests for these cell lots yielded ratios in the range of 1.40 to 1.72:1.00, except for the Lot 8 cells which had a measured ratio of 1.83, due to excessively high negative plate loadings. Precharge capacity on the negative plates generally ranged from 0.7 to 1.1 Ah. Lot 8 negative precharge was 1.35 Ah due to higher loaded negative plates.

SMS/GOES battery cell performance evaluation test results summarized in Appendix G identify circumstances where excessive pressures in Lot 3 production cells weakened the cell plate tab-to-terminal spade welds and caused an increase in the cell internal resistance. Failure analysis of spade weld areas on other cells from Lots 2, 3, and 6 by the GSFC Materials Engineering Branch showed incomplete fusion in the Lots 3 and 6 plate tabs at the tab-to-terminal spade weld interface. It was determined that the weld schedule used for the Lot 3 and 6 cells was established for earlier production cells which had a combination of Inconel and nickel plate tabs. All Lot 6 cell plate tabs were found to be high in nickel content,

Table 3-5. Lot 1 Engineering Cell Manufacturing Data

	Typical Values
Negative loading (g/dm^2)	14.3
Negative group weight (g)	49.9
Negative group thickness (mm)	8.2
Positive loading (g/dm^2)	12.8
Positive group weight (g)	39.4
Positive group thickness (mm)	6.8
Core thickness (mm)	19.2
Electrolyte fill (cc)	12.9
Finished cell weight (g)	154.4
Starved negative capacity (Ah)	6.45
Starved positive capacity (Ah)	4.41
Negative power discharge (Ah)	1.18
Measured negative precharge (Ah)	0.98*
Negative to positive ratio	1.46
Discharged excess negative (Ah) (electrochemically available)**	1.06

*Power discharge at 0.075 A for 13 hours yielded a negative precharge measurement of 1.18 Ah. Power discharge was then continued at 0.100 A for 2 hours, resulting in a calculated negative precharge of 0.98 Ah.

**Starved negative capacity – starved positive capacity – measured precharge = discharged excess negative.

whereas 8 of 11 Lot 2 cell tabs contained a composition comparable to that of Inconel, 750 or 751. The Lot 3 sample had a weld in the tab area but no fusion between the tabs and the nickel saddle. Only one of these tabs was nickel and the remaining were an Inconel alloy. Because of differences in the electrical resistivities of these materials, it was concluded that a weld schedule designed for Inconel tabs would generate more heat than that for nickel tabs. It was determined that a pull test on the tabs is not a reliable indication of a good weld in which penetration occurs into both sides of the spade or saddle. Review of the manufacturer's welding processes resulted in the following actions.

Table 3-6. Lot 1 Engineering Cell Test Data

	Typical Value	Requirement
Conditioning cycle 2 capacity (Ah)	4.45	N/A
24°C C/10 charge for 20 hours		
Peak voltage (V)	1.420	1.46 max
Peak pressure ($10^{-3}N/mm^2$) (lb/in^2)	55.2 (8)	517 max (75 max)
C/2 capacity (Ah)	4.52	3.60 min
35°C C/10 charge for 20 hours		
Peak voltage (V)	1.380	1.39 max
Peak pressure ($10^{-3}N/mm^2$) (lb/in^2)	234 (34)	517 max (75 max)
C/2 capacity (Ah)	2.83	2.00 min
0°C C/20 charge for 48 hours		
Peak voltage (V)	1.515	1.52 max
Peak pressure ($10^{-3}N/mm^2$) (lb/in^2)	117 (17)	517 max (75 max)
C/2 capacity (Ah)	3.98	3.00 min
24°C C/10 charge for 20 hours		
Peak voltage (V)	1.451	1.46 max
Peak pressure ($10^{-3}N/mm^2$) (lb/in^2)	124 (18)	517 max (75 max)
C/2 capacity (Ah)	4.20	3.60 min
Charge retention voltage (V)	1.212	1.16 min
Starved positive ECT (Ah)	4.41	
Starved negative ECT (Ah)	6.45	
Flooded positive ECT (Ah)	4.72	
Flooded negative ECT (Ah)	7.42	

Table 3-7. Flight Cell Manufacturing Data

	Lot 1	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 10	Lot 12
Negative loading (g/dm^2	14.3	14.4	14.4	14.1	14.1	13.3	16.0	15.0	15.0
Negative group weight (g)	49.9	49.8	49.8	48.5	48.3	48.2	53.9	50.5	50.4
Negative group thickness (mm)	8.2	8.3	8.3	7.2	7.2	8.3	8.8	8.0	7.9
Positive loading (g/dm^2)	12.8	11.3	11.3	12.7	12.7	12.5	12.8	12.3	12.3
Positive group weight (g)	39.4	38.6	38.6	40.3	40.6	40.7	39.9	39.7	39.8
Positive group thickness (mm)	6.8	6.4	6.4	6.5	6.5	6.9	6.9	6.8	6.8
Core thickness (mm)	19.2	18.0	18.7	18.4	18.5	19.6	19.8	18.8	18.4
Electrolyte fill (cc)	12.9	15.0	13.6	12.3	12.3	12.3	12.8	12.3	12.3
Finished cell weight (g)	154.4	150.0	150.5	151.0	150.0	150.0	156.4	153.2	154.0
Starved negative capacity (Ah)	6.45	5.40	5.66	6.64	6.18	6.20	8.39	6.53	6.40
Starved positive capacity (Ah)	4.41	3.43	3.65	4.31	4.43	4.39	4.59	3.80	3.95
Negative power discharge (Ah)	1.18	1.13	1.05	1.28	1.28	1.09	2.25	1.60	1.60
Measured negative precharge (Ah)	0.98	1.00	0.40	1.03	0.68	0.89	1.35	1.11	0.91
Negative to positive ratio	1.46	1.57	1.55	1.54	1.40	1.41	1.83	1.72	1.62
Discharged excess negative (Ah) (electrochemically available)*	1.06	0.97	1.61	1.30	1.07	0.92	2.45	1.62	1.54

*Starved negative capacity — starved positive capacity — measured precharge = discharged excess negative.

- Welding areas on the cell terminal spade lugs are mechanically cleaned prior to saddle welding.
- Pull tests are performed on saddle welds to verify weld penetration into the saddle.
- Saddle welds are sectioned on a random basis and examined for fusion upon completion of all production runs.

VENDOR ACCEPTANCE TEST RESULTS

Vendor cell acceptance test results for cells from production Lots 1, 3, 5, 6, 7, 8, 10, and 12 are summarized in Table 3-8. The vendor acceptance test procedures are included in Appendix H.

Eagle Picher cell acceptance tests for three temperature conditions show that cell capacity is more divergent at 35°C than for other test temperatures. At 35°C the typical capacity range was from 2.54 to 3.43 Ah. The data indicate that cell Lots 8, 10, and 12 had higher positive plate charge acceptance at elevated temperatures, compared with cell Lots 1, 5, 6, and 7. The cell capacity ranges for 0 and 24°C typically were 3.61 to 4.26 Ah, and 3.95 to 4.37 Ah, respectively. Cell Lots 5, 10, and 12 had relatively lower 0°C overcharge peak voltages, typically 1.47 to 1.48 volts maximum. These lots also had generally higher levels of discharged excess negative capacity with the exception of Lot 8 which was excessively high due to high

Table 3-8. Flight Cell Acceptance Test Data

Vendor Cell Parameter	Lot 1	Lot 3	Lot 5	Lot 6	Lot 7	Lot 8	Lot 10	Lot 12
C/2 Conditioning Cycle 2 Capacity (Ah)	4.45	3.56	3.90	4.09	4.47	4.55	4.24	4.07
24°C C/10 Charge for 24 Hours								
Peak Voltage (V)	1.43	1.44	1.43	1.43	1.43	1.44	1.44	1.44
Peak Pressure								
(10^{-3} N/mm^2)	41.4	234	103	138	68.9	138	117	82.8
(lb/in^2)	(6)	(34)	(15)	(20)	(10)	(20)	(17)	(12)
C/2 Capacity (Ah)	4.52	3.60	3.94	4.02	4.05	4.36	4.32	4.33
35°C C/10 Charge for 20 Hours								
Peak Voltage (V)	1.38	1.39	1.38	1.38	1.38	1.39	1.39	1.39
Peak Pressure								
(10^{-3} N/mm^2)	234	386	407	462	496	483	172	172
(lb/in^2)	(34)	(56)	(59)	(67)	(72)	(70)	(25)	(25)
C/2 Capacity (Ah)	2.83	2.66	2.60	2.63	2.54	3.00	3.37	3.43
0°C C/20 Charge for 48 hours								
Peak Voltage (V)	1.51	1.51	1.48	1.50	1.52	1.51	1.47	1.47
Peak Pressure								
(10^{-3} N/mm^2)	103	241	138	207	103	324	228	221
(lb/in^2)	(15)	(35)	(20)	(30)	(15)	(47)	(33)	(32)
C/2 Capacity (Ah)	3.98	3.57	3.81	3.85	4.26	4.26	3.77	3.61
24°C C/10 Charge for 20 Hours								
Peak Voltage (V)	1.44	1.45	1.44	1.45	1.42	1.43	1.44	1.43
Peak Pressure								
(10^{-3} N/mm^2)	159	365	152	117	96.5	152	200	234
(lb/in^2)	(23)	(53)	(22)	(17)	(14)	(22)	(29)	(34)
C/2 Capacity (Ah)	4.20	3.55	3.95	4.01	3.98	4.37	4.15	4.15

Overcharge pressure at 0°C for Lot 8 cells was typically $351.6 \times 10^{-3} N/mm^2$ ($51 lb/in^2$), while the other cell lots had pressure values ranging from $103.4 \times 10^{-3} N/mm^2$ ($15 lb/in^2$) to $241.3 \times 10^{-3} N/mm^2$ ($35 lb/in^2$).

OTHER MANUFACTURING DATA

Nonwoven nylon filament material (Pellon #2505 ML) used as the separator is supplied by the roll with traceability to the manufacturer's style, lot number, and roll number. Individual rolls consist of one continuous (unspliced) sheet which may be used for more than one cell manufacturing lot. Wetting agents or antistatic agents which cause foaming or are unstable in strong alkali are eliminated by extra washing in the separator manufacturing processes. Separator tests described in Appendix E and summarized in Table 3-9 include the following:

- Electrolyte absorption, retention, and porosity
- Tensile strength at break
- Extractable organic content
- Inorganic content
- Discoloration of samples in electrolyte
- Thickness variation
- Separator resistance and resistivity
- Separator wettability

Results of the separator physical properties measurements indicate relatively wide variation in values which may be attributed to test measurement error or manufacturing variables.

Table 3-9. SMS/GOES Battery Cell Separator Test Data

	Cell Manufacturing Lot Number			
	1 & 3	5 & 6	7 & 8	10 & 12
*Para. 20.1.4 Electrolyte Retained (gms)	0.69	1.00	0.63	0.56
*Para. 20.1.4 Electrolyte Retained (%)	129	130	75	85
*Para. 20.1.5 Porosity (%)	71	161	223	205
*Para. 20.2.1 Tensile Strength at Break (lb)	1.8	3.2	4.1	4.9
*Para. 20.2.1 Elongation at Break (%)	16	10	20	23
Ignition Residue of Pellon (%)	0.68	0.59	0.17	0.20
Methanol Extraction of Pellon (%)	1.84	1.70	0.51	0.58
Inorganic Extracted with H_2O, expressed as % of Pellon				
Cl	0.13	0.21	0.10	0.18
Si	< 0.02	< 0.02	< 0.02	< 0.02
Zn	0.09	0.20	0.01	0.01
NO_3	< 0.02	< 0.01	< 0.01	< 0.01
Ni	< 0.02	< 0.0005	< 0.0005	< 0.0005
Ti	< 0.02	< 0.0002	< 0.0002	< 0.0002

*See Specification SP-212064, Appendix E.

SECTION 4

BATTERY DEVELOPMENT AND QUALIFICATION

A primary objective of the battery development program at FACC was to verify that the selected battery cell design would meet performance requirements described in Section 2. Battery cell development testing was conducted to verify vendor test results and to characterize cell temperature/capacity performance. FACC screening tests (included in Appendix I) were not performed on the Lot 1 cells used in assembly of the engineering and qualification test batteries. This section documents development cell test results and summarizes various battery assembly processes. Also included are results of the engineering and qualification battery tests.

FACC 12-CELL CHARACTERIZATION TEST

Development testing of the flight configuration battery cells included electrical performance measurements of cell capacity at various temperatures and simulated synchronous orbit cycles at typical spacecraft operating temperatures. Three basic tests were performed on 12 Lot 1 cells as follows:

- Cell discharge capacity measurements
- Accelerated 12-hour charge/discharge cycling
- Low temperature overcharge voltage measurements

A summary of the FACC Lot 1 development cell testing is included in Appendix J. The cells successfully completed capacity testing at 20, 0, and 35°C and were then subjected to an accelerated 33-cycle synchronous orbit test simulation consisting of a 10.8 hour charge at 0.3 amp and a 1.2 hour discharge at 1.5 amps. All cells exceeded the minimum allowable voltage of 1.16 volts per cell at the end of each 1.2 hour discharge period. The cells were subsequently overcharged at 0.15 amp at 2°C. The average peak cell overcharge voltage for this test was 1.543 volts. Test results other than for the final 2°C overcharge test were considered acceptable. Table 4-1 provides a general summary of the 12-cell development programs.

Upon completion of the 12-cell development program, the remaining Lot 1 cells were matched for use in the engineering and qualification batteries S/N 1001 and 1002 based on vendor 24°C capacity test results. The allowable range utilized was ±1.0 percent of the mean cell capacity, as shown in Table 4-2.

Battery fabrication begins with selection of 20 cells in accordance with matching requirements specified in the Battery Design Specification SD-212066 (included in Appendix A). The cells are degreased in fluid methylene chloride and rinsed in methyl alcohol. The cells are masked and painted with a flat black Chemglaze and then fitted with 0.076 mm mylar insulating jackets. Final assembly is accomplished as described in the following paragraph and the Battery Assembly Procedure SC-213772 (included in Appendix K).

Table 4-1. 12-Cell Characterization Test Data Summary

Test Description		Test Data
20°C	C/10 charge for 48 hours	
	Peak voltage (V)	1.463
	C/2 minimum capacity (Ah)	4.50
20°C	C/10 charge for 20 hours	
	Peak voltage (V)	1.465
	C/2 minimum capacity (Ah)	4.20
0°C	C/20 charge for 47 hours	
	Peak voltage (V)	1.560
	C/2 minimum capacity (Ah)	3.40
35°C	C/10 charge for 23 hours	
	Peak voltage (V)	1.393
	C/2 minimum capacity (Ah)	2.77
	Accelerated Synchronous Orbit Cycling	
20°	Cycle 11 minimum voltage (V)	1.221
15°C	Cycle 20 minimum voltage (V)	1.217
30°C	Cycle 33 minimum voltage (V)	1.190
2°C	Post cycling C/20 charge for 27 hours (following C/10 charge for 20 hours at 20°C)	
	Peak voltage (V)	1.582

The cells, support T-ribs, endplates, and nut and bolt assemblies are prealigned in a battery assembly alignment fixture. Following tightening of the bolt assemblies to an endplate restraining pressure of 0.66 N/mm^2 (96 lb/in^2), safety wire is attached to the endplate and the battery placed into a mounting hole drilling fixture. After the mounting holes are drilled, epoxy base resin cell support blocks are epoxied in place on the T-ribs. The assembly is thermal vacuum dried at 32°C in a vacuum of 36 mm Hg. The battery is then painted with a flat black Chemglaze and a prewired connector is installed on the connector endplate. Intercell wiring is completed and final inspection performed. Documentation of the physical characteristics is completed and the battery placed in storage. Table 4-3 summarizes battery assembly documentation used by FACC for this development program.

ENGINEERING BATTERY DEVELOPMENT TESTS

Two engineering batteries, S/N 1001 and 1002, were subjected to development testing in accordance with the Battery Assembly Development Test Procedure SC-225293. The basic test program is similar to the standard battery acceptance tests and consists of the following functional tests and inspections:

- Examination of product
- Insulation resistance measurement
- Electrolyte leakage inspection
- Battery electrical reconditioning
- Cell charge retention measurement
- Battery capacity measurement at 24, 33, and 2°C
- Battery overcharge voltage measurement at 2°C
- Electrolyte leakage inspection
- Insulation resistance measurement

Results of these tests are summarized in Table 4-4.

A review of the data summary in Table 4-4 shows that the engineering batteries successfully completed the development test sequence. Following completion of the development tests, battery S/N 1002 was prepared for qualification testing as summarized in the following pages.

Table 4-2. Engineering Battery Cell Capacity Matching Data (Battery S/N 1001 and 1002)

Cell S/N	24°C Capacity (Ah)	Cell S/N	24°C Capacity (Ah)
13	4.13	14	4.20
16	4.18	15	4.25
19	4.13	17	4.20
21	4.18	18	4.23
23	4.10	22	4.25
29	4.13	24	4.20
32	4.10	25	4.20
34	4.15	26	4.25
35	4.10	27	4.23
36	4.13	28	4.23
37	4.15	30	4.25
38	4.15	31	4.25
43	4.18	39	4.28
46	4.18	41	4.20
49	4.15	44	4.25
51	4.15	45	4.25
57	4.13	47	4.25
59	4.15	48	4.20
61	4.10	50	4.25
62	4.10	52	4.23
64*	4.15	53*	4.23
65*	4.15	54*	4.23
Capacity Range	4.10/ 4.18	Capacity Range	4.20/ 4.28
Tolerance	±1.0%	Tolerance	±1.0%

*Spare cells

BATTERY QUALIFICATION TESTS

The qualification battery S/N 1002 testing was conducted in accordance with the Battery Assembly Qualification Test Procedure SY-212789. The fundamental test program consisted of the following functional tests and inspections:

- Examination of product
- Insulation resistance measurement
- Electrolyte leakage inspection
- Battery electrical reconditioning
- Battery thermistor measurement
- Battery capacity measurements at 20, 2, and 33°C
- Random and sinusoidal vibration environments with discharge voltage measurements and visual damage inspection
- Battery post-vibration capacity measurements at 20°C and insulation resistance measurement
- Sustained acceleration environment with discharge voltage measurement and visual damage inspection

- Battery post-acceleration capacity measurement at 20°C and insulation resistance measurement
- Thermal vacuum thermistor measurement and battery discharge/charge voltage measurements at 33, 20, and 2°C
- Post-vacuum insulation resistance measurement
- Battery discharge voltage pulse load measurement
- Battery full charge voltage measurement at 30 and 10°C
- Battery cell charge retention measurement
- Electrolyte leakage inspection

Table 4-3. SMS/GOES Battery Assembly Documentation

Title	Document No.
Cell Procurement Specification	SP 212064
Cell Statement of Work	SW 212065
Battery Assembly Drawings	213827
Battery Design Specification	SD 212066
Battery Design Review Report	PCC-3763
Battery Assembly Procedure	SC 213772
Battery Disassembly Procedure	SV 225240
Battery Development Test Procedure	SC 225293
Battery Qualification Test Procedure	SY 212789
Battery Cell Screening Procedure	SC 213728
Battery Acceptance Test Procedure	SB 213716
Development Report	TR 5008
Qualification Report	TR 5026
Design Review Report	TR 5041

QUALIFICATION TEST RESULTS

The battery successfully completed all capacity temperature measurements at 20, 2, and 33°C, as shown in the Qualification Test Detailed Summary (included in Appendix L). The discharge capacities were, respectively, 3.84, 3.52, and 2.24 Ah. These values compare favorably with minimum allowable values of 3.0, 2.25, and 1.5 Ah.

The battery was subjected to random and sinusoidal vibration environments in accordance with Procedure SY-212789 and Table 4-5. Following the successful completion of vibration testing, the unit was inspected for visible damage and a 20°C capacity measurement made. The measured capacity was 3.59 Ah. Prior to sustained acceleration testing, the battery insulation resistance measurements were recorded. The minimum resistance value measured was 100 mΩ. This value compares with a minimum allowable resistance of 10 mΩ.

The battery was then subjected to a sustained acceleration environment. After completing five of the six axis orientation tests, a test equipment malfunction was encountered. The test harness connecting lead wires were inadvertently shorted momentarily, resulting in a burn on battery cell voltage sense lead wires for battery cells 1 and 4. Following replacement of the battery connector and associated wiring, the battery was given a 20°C capacity cycle. The capacity measurement resulted in a measured capacity value of 3.54 Ah, which agreed well with the post-vibration measurement of 3.59 Ah. After completing the sustained acceleration test, the battery was inspected for visual damage and was subjected to a 20°C capacity measurement. The battery delivered 3.72 Ah.

In preparation for thermal vacuum testing, the battery was mounted in a vacuum chamber with a thermally controllable baseplate. Three battery thermistor calibration measurements were made after temperature stabilization periods of 16.0 hours at 2, 33, and 20°C in a

Table 4-4. Results of Engineering Battery Development Test Program

	S/N 1001	S/N 1002	Requirement
Examination of Product			
Workmanship	Acceptable	Acceptable	MIL-STD 454
Construction	Acceptable	Acceptable	SD-212066
Interchangeability	Acceptable	Acceptable	DWG 213827
Weight	3.41 kg	3.42 kg	3.59 kg max
Insulation Resistance	>100 m Ω	>100 m Ω	⩾100 m Ω
Electrolyte Leakage	Colorless	Colorless	Colorless
Reconditioning	4.35 Ah	4.63 Ah	3.0 Ah
	4.20 Ah	4.30 Ah	3.0 Ah
Charge Retention	1.200 V	1.207 V	⩾1.16 V
C/2 Capacity +24°C	4.00 Ah	4.24 Ah	3.0 Ah
C/2 Capacity +33°C	2.76 Ah	2.70 Ah	1.50 Ah
C/2 Capacity +2°C	3.33 Ah	3.39 Ah	2.25 Ah
C/2 Capacity +24°C	3.81 Ah	3.86 Ah	3.00 Ah
C/20 Overcharge +2°C	30.65 V/Bat	30.66 V/Bat	
	1.545 V/Cell	1.540 V/Cell	⩽1.55 V/Cell
Electrolyte Leakage	Colorless	Colorless	Colorless
Insulation Resistance	>100 m Ω	⩾100 m Ω	⩾100 m Ω

vacuum of $\leq 1.0 \times 10^{-5}$ torr. The battery was discharged at a 1.5 amp rate for one minute after each temperature stabilization and charged for 10 minutes (at a 0.15 amp rate at 2°C and 0.3 amp rate at 33 and 20°C).

The post-thermal vacuum functional performance tests were initiated with the battery fully charged. The battery was discharged at a 1.5 amp rate for 30 minutes and then subjected to two pulse load conditions, a 10.0 amp load for 5.0 minute period, followed by a 25.0 amp load for 10.0 seconds. The minimum battery and battery cell voltage for the 10.0 and 25.0 amp loads were 21.48 volts (1.070 volts per cell), and 20.13 volts (1.012 volts per cell), respectively.

The final functional test consisted of overcharge voltage measurements at 30 and 10°C. The fully charged battery was stabilized at each test temperature and then overcharged for a period of 4.0 ± 0.5 hours. The charge rate was 0.3 amp at 30°C and 0.2 amp at 10°C. The battery successfully passed these tests with a maximum battery voltage of 27.69 volts (1.392 volts per cell) and 29.58 volts (1.490 volts per cell) for test temperatures at 30 and 10°C, respectively.

ENGINEERING AND QUALIFICATION TEST RESULTS SUMMARY

The battery assembly sucessfully passed qualification level vibration and acceleration

Table 4-5. SMS/GOES Battery Qualification Sinusoidal Vibration

Description	Frequency Range (Hz)	Level "g" (0 to Peak)	Test Sweep (Oct/Min)	Design Sweep (Oct/Min)
Components on Equipment Panel (XX, YY)	5–10	0.5" DA	4.0	2.0
	10–20	10.0		
	20–25	4.0		
	25–40	8.0		
	40–100	4.0		
	100–200	2.0		
	200–2000	5.0		
Components on Equipment Panel (ZZ)	5–11	0.5" DA	4.0	2.0
	11–13	7.0		
	13–30	12.5		
	30–60	25.0		
	60–70	15.0		
	70–110	8.0		
	110–200	3.0		
	200–2000	5.0		

environments, establishing the integrity of the structural components and verifying the analytical design margins.

The measured maximum temperature gradients within the battery during thermal vacuum temperature performance tests was 1.6°C at 30°C and 1.7°C at 10°C. These values compare favorably with the expected temperature gradient of 2.0°C for these test conditions.

Discharge capacity performance for both the engineering and qualification batteries was excellent over the test temperature range of 2 to 33°C. Maximum battery cell charge voltage for the final low temperature 2°C overcharge test was 1.545 volts during development tests. This value was somewhat higher than desired but within the specified limit. Based upon development and qualification test data, the battery cell and battery assembly designs were finalized for flight hardware production.

SECTION 5

FLIGHT BATTERY FABRICATION, ASSEMBLY, AND TEST

Specifications and manufacturing processes used in the testing of the battery cells and the production of batteries are documented in this section. Results of cell characterization testing per the battery cell screening procedure are summarized. Also summarized are the FACC battery acceptance test results. Investigation of possible correlation between these data and manufacturing process variations is evaluated as a part of the mission performance analysis described in Section 6.

SUMMARY OF THE BATTERY MANUFACTURING FLOW

Cells are subjected to screening tests following procurement in accordance with the Procurement Specification SP-212064 (included in Appendix E). Battery assemblies are fabricated with selected cells and then battery acceptance tests are performed. The batteries are then placed in storage at a temperature between 0 and 5°C in the fully discharged shorted condition. Prelaunch activation is performed prior to delivery of batteries for spacecraft integration. The battery manufacturing and test flow is shown in Figure 5-1.

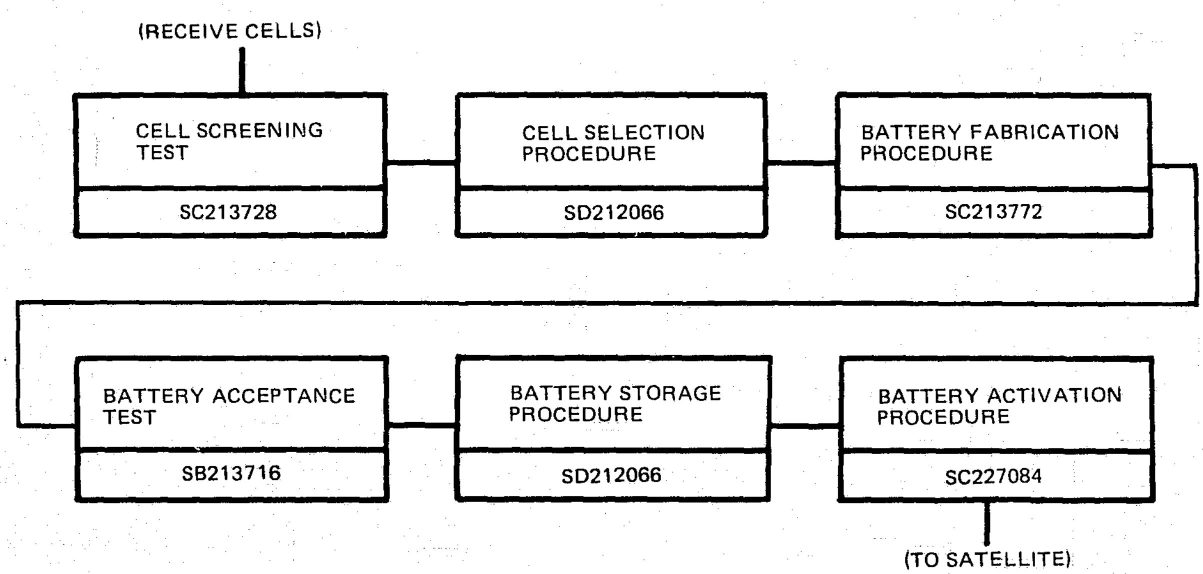

Figure 5-1. SMS/GOES Battery Manufacturing and Test Flow

LABORATORY TEST AND FABRICATION EQUIPMENT

Battery cell and battery assembly tests are performed with a standard equipment configuration utilized for flight hardware evaluation, as depicted in the test setup diagram shown in Figure 5-2. The Bench Test Equipment (BTE) can automatically cycle the battery cells or battery assemblies, as required. The system provides a constant current charge/discharge

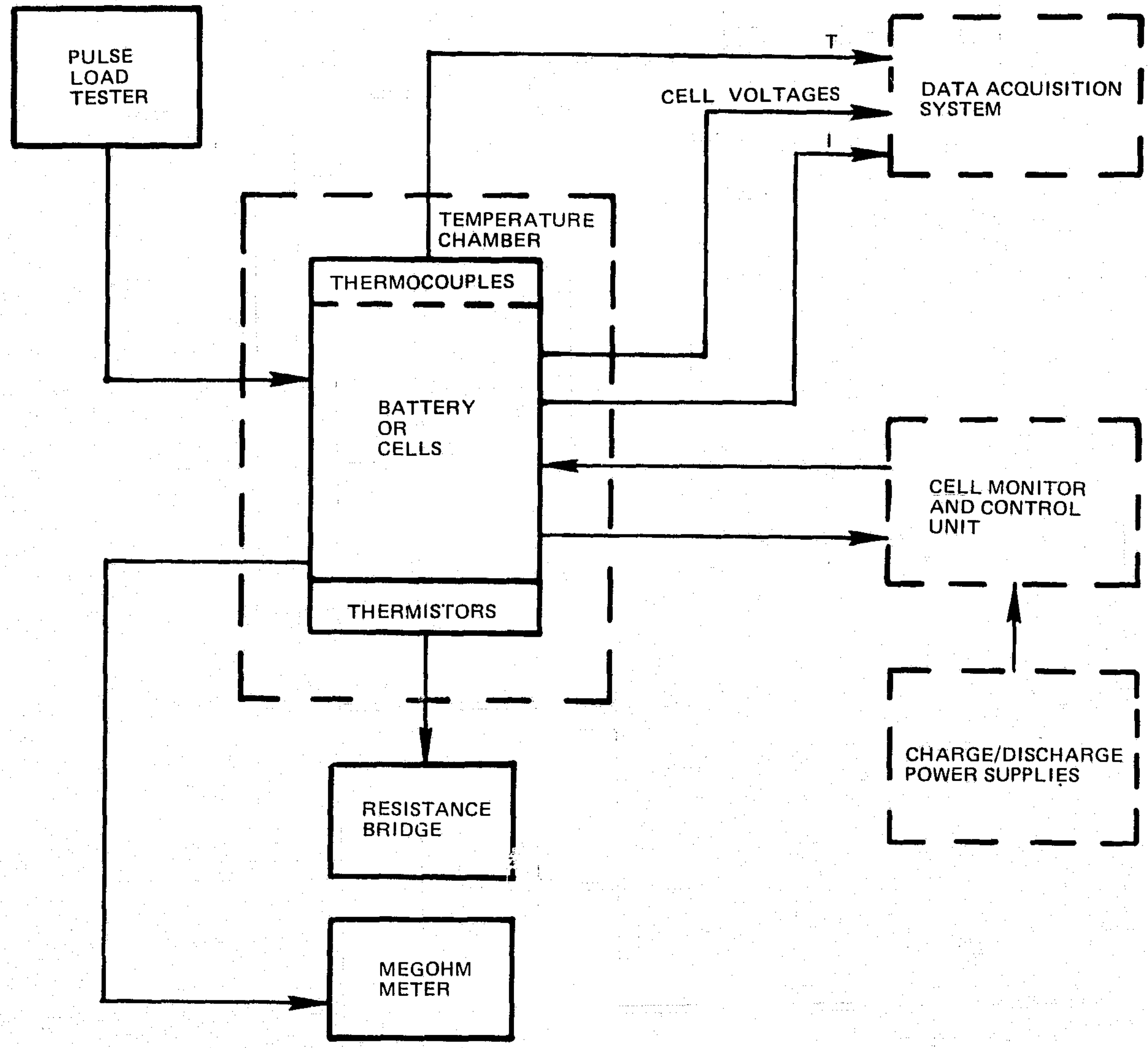

Figure 5-2. Battery Cell and Battery Test Setup

circuit with an automatic cell and battery undervoltage trip-out circuit. Test parameters such as voltage, current, and temperature are recorded on digital recorder printout tape for transfer to a magnetic tape or punch cards.

The BTE has two test control units and a data recorder bank, as illustrated in Figure 5-3. Batteries or cells are electrically tested at specified temperatures with environmental chambers and large heat sinks.

Battery cell evaluation begins with cell restrainer installation on the equipment mounting panel. Electrical access to the cells is provided with hardwire connection to the equipment panel plug. Following cell screening tests, a group of cells is selected for processing and battery assembly. Battery assembly is conducted in a low dust environment provided by a positive flow bench.

BATTERY CELL SCREENING TESTS

The Battery Cell Screening Procedure SC-213782 is included in Appendix I. The principal steps included in this test sequence are:

- Examination of product
- Electrolyte leakage
- Electrical reconditioning
- Charge retention
- Capacity cycles (burn-in)
- Capacity, 20°C
- Capacity, 2°C
- Capacity, 33°C
- Pulse load
- Electrolyte leakage

Cell screening is performed to characterize and stabilize cell performance. Cell performance variation is minimized in the battery assembly by carefully selecting cells with similar capacity and peak charge voltage characteristics. Battery cells for the first three flight batteries S/N 1005, 1006, and 1007 were subjected to capacity temperature tests and then burn-in cycled. Because these cells later exhibited divergent charge voltages, this procedure was reversed to improve battery assembly cell voltage matching prior to unit fabrication. Table 5-1 summarizes the plan utilized for flight cell testing at FACC.

SCREENING TEST RESULTS

Cell performance test results for 13 SMS/GOES batteries are summarized in Table 5-2 and Figure 5-4. Low-temperature (2°C) capacity test overcharge voltage performance for GOES-B Lot 10 battery cells (S/N 1013, 1014, 1015) was generally superior to all other groups, with a mean peak voltage of 1.511 volts. SMS-A Lot 5 battery cells (S/N 1007) also exhibited a low mean peak voltage of 1.508 volts.

GOES-C Lot 12 battery cells (S/N 1020 and 1021) also exhibited good low temperature peak voltage characteristics with a typical 1.513 volts. Other groups of cells had slightly higher charge voltages for the same test, ranging from 1.522 volts to 1.545 volts. Excluding

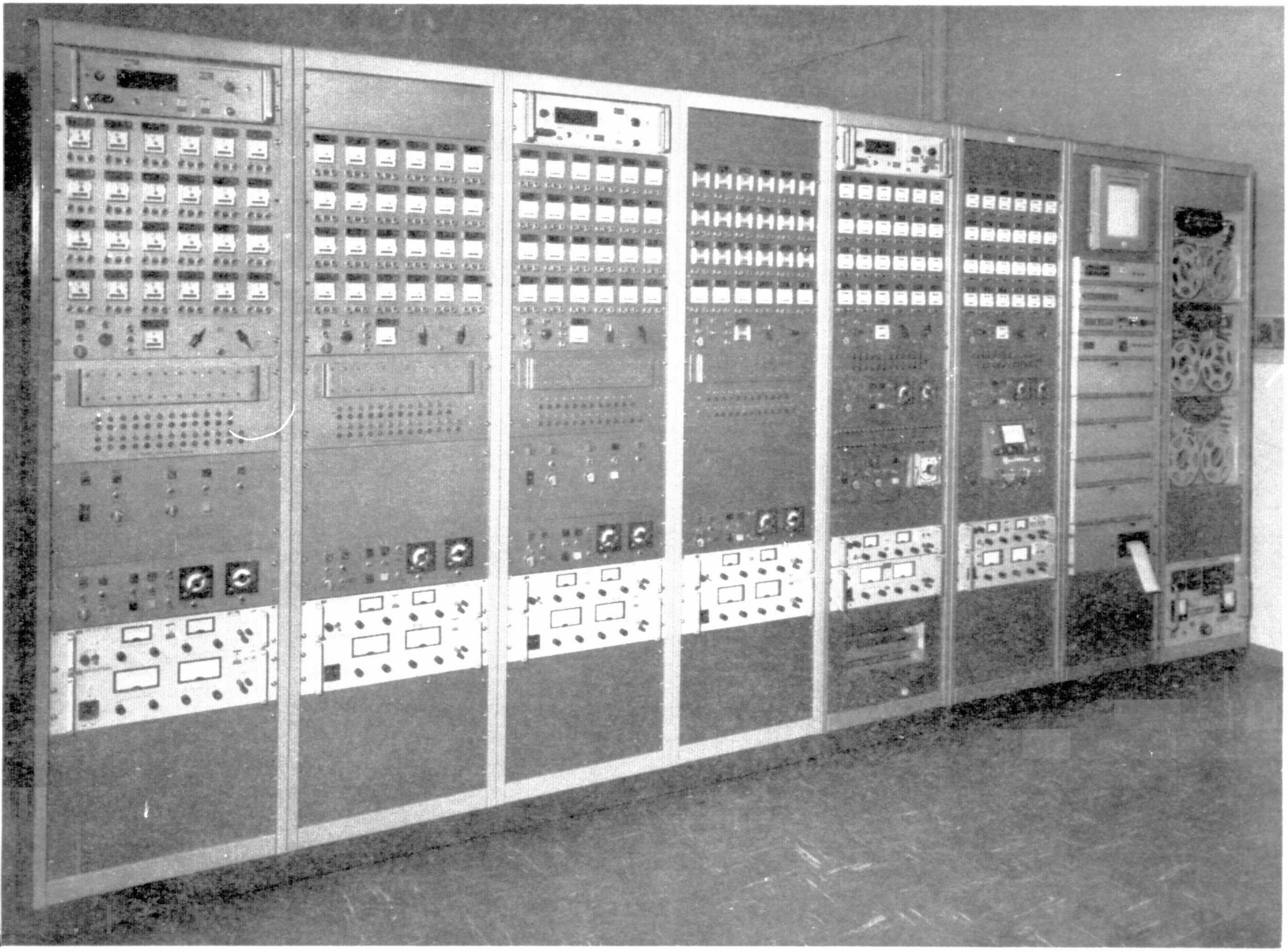

Figure 5-3. Battery Electrical Testing Facilities

Table 5-1. Battery Cell Screening Test Matrix

Test \ Performance Parameter	Identification	Dimension	Weight	Interchangeability	Construction	Workmanship	Electrolyte leakage	Recondition	Charge retention	Capacity	Low temperature capacity	High temperature capacity	Capacity cycle	Pulse load	Electrolyte leakage
Examination of product	X	X	X	X	X	X									
Leakage							X								
Functional								X	X	X	X	X	X	X	
Leakage															X

Lot 8 battery cells (S/N 1010, 1011, 1012), cells with increased overcharge protection in the form of discharged excess negative generally exhibited improved low temperature maximum charge voltages, as shown in Table 5-3. It appears that high negative plate loading (16.0 g/dm^2) for Lot 8 cells caused poor active material utilization and decreased overcharge protection.

CELL SELECTION FOR BATTERY FABRICATION

The SMS/GOES battery assembly capacity matching performance requirements are defined in Table 5-4. Other selection criteria which are also considered in selection of a group of cells for fabrication of a battery are cell manufacturing lot and physical properties, such as cell thickness and weight.

Table 5-5 identifies the SMS/GOES batteries by serial number, cell manufacturing lot, and designated spacecraft use. A completed battery assembly is shown in Figure 5-5.

FLIGHT BATTERY ACCEPTANCE TESTING

Following fabrication, each flight battery assembly was acceptance tested in accordance with the Battery Assembly Acceptance Test Procedure SB-213716 (included in Appendix M). The test matrix for acceptance testing of the batteries is shown in Table 5-6. This test sequence includes the following basic tests and inspections:

- Examination of product
- Functional performance

Table 5-2. SMS/GOES Battery Cell Screening Test Data

Battery S/N Cell (Mfg Lot)	LT Capacity Test		HT Capacity Test		RT Cycle Test		RT Capacity Test		Pulse Load
	Peak Voltage (a)	Capacity	Peak Voltage	Capacity	Peak Voltage	Capacity	Peak Voltage	Capacity	Min Voltage
	1.515	3.63	1.398	3.25	1.417	3.90	1.473	4.13	1.134
1005	1.527	3.77	1.410	3.58	1.427	4.07	1.485	4.17	1.150
(6)	1.545	3.99	1.424	3.93	1.439	4.25	1.510	4.22	1.169
	1.502	3.41	1.398	3.24	1.413	3.78	1.470	4.01	1.124
1006	1.522	3.66	1.409	3.51	1.421	3.97	1.488	4.09	1.138
(6)	1.545	3.90	1.424	3.78	1.435	4.34	1.497	4.13	1.171
	1.500	3.62	1.394	3.08	1.427	3.95	1.466	4.09	1.127
1007	1.508	3.82	1.402	3.44	1.431	4.04	1.479	4.17	1.140
(5)	1.520	3.90	1.410	3.66	1.436	4.07	1.496	4.23	1.164
	1.534	4.17	1.385	2.48	1.425	3.51	1.462	4.16	1.150
1008	1.540	4.28	1.389	2.65	1.420	3.62	1.476	4.28	1.162
(7)	1.545	4.35	1.394	2.88	1.426	3.72	1.487	4.35	1.178
	1.531	4.07	1.381	2.39	1.414	3.30	1.463	4.08	1.136
1009	1.545	4.26	1.389	2.67	1.419	3.53	1.485	4.25	1.152
(7)	1.558	4.46	1.397	2.87	1.423	3.71	1.499	4.34	1.177
	1.517	3.90	1.398	3.03	1.427	3.99	1.454	4.31	1.161
1010	1.524	4.02	1.404	3.43	1.435	4.17	1.464	4.37	1.169
(8)	1.531	4.19	1.409	3.74	1.441	4.32	1.478	4.44	1.175
	1.520	3.96	1.394	3.09	1.435	3.96	1.460	4.32	1.163
1011	1.525	4.14	1.398	3.35	1.438	4.18	1.469	4.39	1.170
(8)	1.533	4.32	1.403	3.63	1.441	4.31	1.475	4.44	1.176
	1.520	4.10	1.395	3.26	1.436	4.05	1.460	4.34	1.162
1012	1.527	4.23	1.399	3.43	1.439	4.25	1.468	4.39	1.173
(8)	1.534	4.43	1.403	3.63	1.441	4.34	1.477	4.46	1.182
	1.512	3.74	1.412	3.59	1.430	4.11	1.470	4.19	1.143
1013	1.519	3.96	1.421	3.75	1.436	4.22	1.476	4.25	1.150
(10)	1.526	4.10	1.431	3.89	1.439	4.25	1.480	4.34	1.157
	1.498	3.71	1.420	3.75	1.430	4.04	1.464	4.13	1.129
1014	1.507	3.85	1.435	3.96	1.437	4.14	1.470	4.19	1.143
(10)	1.516	3.96	1.445	4.05	1.442	4.23	1.478	4.23	1.157
	1.500	3.80	1.421	3.84	1.431	4.11	1.467	4.20	1.134
1015	1.508	3.90	1.435	3.97	1.438	4.17	1.472	4.24	1.146
(10)	1.515	4.08	1.446	4.08	1.441	4.26	1.477	4.32	1.160
	1.501	3.80	1.417	3.68	1.431	4.02	1.470	4.17	1.127
1020	1.512	3.91	1.435	3.95	1.440	4.16	1.479	4.21	1.137
(12)	1.525	4.00	1.446	4.10	1.452	4.23	1.483	4.26	1.147
	1.505	3.80	1.414	3.68	1.430	4.07	1.472	4.10	1.129
1021	1.513	3.90	1.431	3.93	1.440	4.17	1.479	4.15	1.138
(12)	1.523	3.99	1.445	4.13	1.452	4.23	1.484	4.17	1.150

(a) The three values in each column are minimum, mean, maximum.

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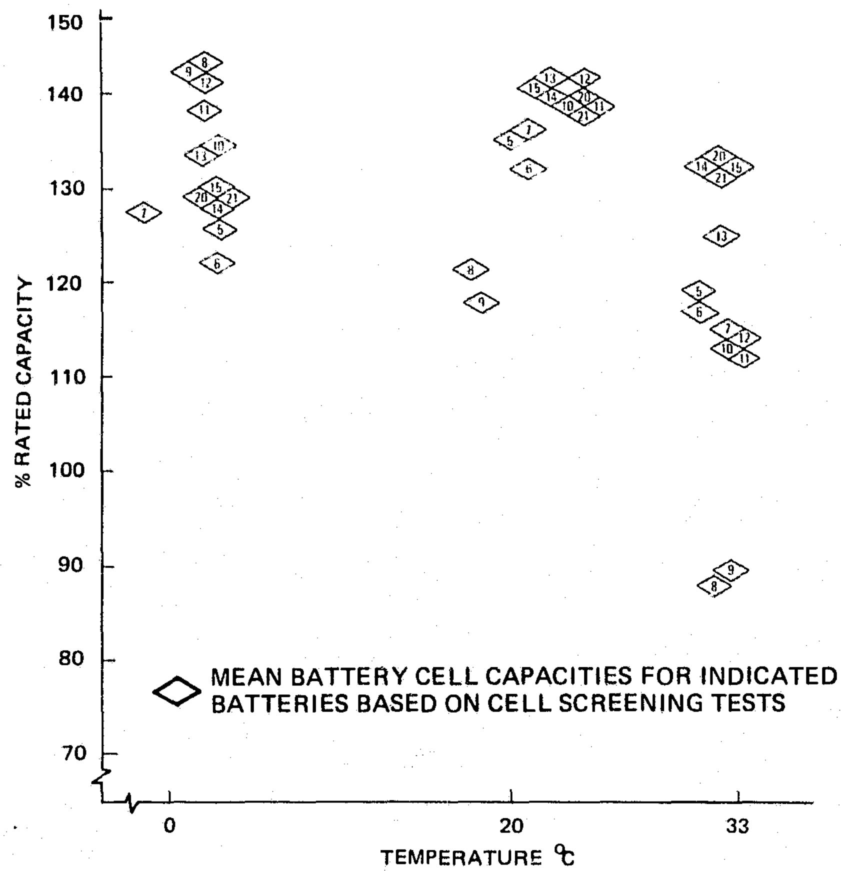

Figure 5-4. SMS/GOES Battery Cell Capacity vs Temperature

- Vibration
- Post-vibration performance
- Thermal vacuum
- Post-thermal vacuum performance

The key functional performance tests include three capacity measurements: 20, 2, and 33°C. The final performance testing encompasses a 20°C capacity measurement, pulse load, thermistor measurement, cell charge retention, assembly insulation resistance, and cell electrolyte leakage inspection.

Battery acceptance test results are summarized in Table 5-7. Figures 5-4 and 5-6 show improved high temperature capacity characteristics for the GOES batteries relative to the SMS batteries. In general, the battery cell manufacturing lots have similar low temperature capacities.

Acceptance Test Voltage Performance

Maximum battery charge voltages recorded during low temperature (2°C) battery capacity tests are summarized in Table 5-8. The battery charge voltage characteristics are plotted

by cell manufacturing lot number in Figures 5-7 and 5-8 against charge current and excess negative capacity. Review of that data shows a possible relationship between battery charge voltage with increased levels of discharged excess negative capacity (except for Lot 8 cells). Cell Lots 5, 10, and 12 have somewhat higher excess negative capacities based upon data summarized in Table 5-3 and plotted in Figure 5-8. It is thought that reduced negative plate utilization is the reason for higher maximum charge voltage characteristics in cell Lot 8.

Table 5-3. SMS/GOES Maximum Battery Cell Voltage Data

Cell Mfg Lot	Discharged Excess Negative Electrochemically Available	Cell Max Voltage 2°C Screening Tests
5	1.30 Ah	1.508 V
6	1.07 Ah	1.524 V
7	0.92 Ah	1.542 V
8*	2.45 Ah	1.525 V
10	1.62 Ah	1.511 V
12	1.54 Ah	1.514 V

*Lot 8 cells contained increased positive and negative electrode active material loadings.

Some initially high cell charging voltages were observed following shorted cell storage periods during Lot 7 and 8 cell screening tests. Initial cell charging voltages ranged from 1.4 to 1.6 volts for a 0.15 amp charge rate at room ambient conditions. The high cell voltages decreased with increased charge time and cycling. Similar anomalous performance was also observed during battery acceptance and activation tests following 1-ohm loading periods on individual cells. Conditions associated with this anomaly were considered unique to ground testing procedures. Orbital performance of batteries S/N 1008, 1011, and 1012 having Lot 7 and 8 cells has been similar to other cell lots which did not exhibit this characteristic. It is felt that the initially high cell charging voltages are the result of an electrolyte distribution problem within the cell. Shorted storage and/or 1-ohm loading periods may cause a redistribution of electrolyte from the cell separator material into the positive electrodes. High internal cell resistance is then encountered when charging is initiated. This resistance decreases as electrolyte is again redistributed during charging, and a resultant decrease in cell charging voltage is observed. It has not been verified why this phenomena is unique to the Lot 7 and 8 cells; however, it may be related to separator dry out

Table 5-4. SMS/GOES Battery Assembly Capacity Performance Requirements

Temp (°C)	Discharge Current (A)	Discharge Time (hours)	Min Voltage (V)	Min Req'd % Rated Cap 100%=3 (Ah)	Max Allowable Cell Capacity Difference (Ah)
24 ± 2	1.5	2.0	20.00	100	0.15
2 ± 2	1.5	1.5	20.00	75	0.30
33 ± 2	1.5	1.0	20.00	50	0.50
5 to 30	1.5	1.7	20.00	85	0.25

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due to increased cell core thickness of approximately 1 mm compared with other cell lots (as noted in Table 3-7). Plate capillary potential tends to cause electrotyte to be selectively retained in the plates, particularly for a condition where the volume of electrolyte is reduced in a fully discharged cell.

BATTERY STORAGE AND ACTIVATION FOR LAUNCH

The SMS/GOES batteries are stored prior to satellite installation in a fully discharged, shorted condition at a low temperature, approximately 0 to 5°C in a dry environment. When required, a battery is removed from storage and electrically activated for use in accordance with Battery Assembly Activation Test Procedure SC-227084. This procedure establishes performance requirements for the activation tests and includes the following inspections, measurements, and test conditions:

- Examination of product
- Functional performance
- Insulation resistance
- Reconditioning
- Capacity, 20°C
- Charge retention
- Electrolyte leakage

Table 5-5. SMS/GOES Battery Spacecraft Assignments

Battery S/N	Cell Mfg Lot	Spacecraft Designation
1005	6	GOES-A
1006	6	SMS-A
1007	5	SMS-A
1008	7	SMS-B
1009	7	Spare
1010	8	Spare
1011	8	SMS-B
1012	8	GOES-A
1013	10	Spare
1014	10	GOES-B
1015	10	GOES-B
1020	12	GOES-C
1021	12	GOES-C

Although results of activation tests are limited in population, it is felt that a potential relationship between increased charge voltage and extended periods of storage, coupled with marginal overcharge capability, may exist for the specific test conditions cited above. Battery S/N 1005 was stored for 24 months and was assembled from Lot 6 cells having reduced discharged excess negative capacity (1.07 Ah) compared with Lots 5, 8, 10, and 12. It exhibited a maximum charge voltage of 29.92 volts during the second activation test reconditioning charge. Battery S/N 1011 was stored for just 4 months and had a reduced charge voltage of 29.06 volts, as shown in Table 5-9. The other batteries storage periods and maximum charge voltages were generally within these extremes.

Cell manufacturing Lots 10 and 12 (battery S/N 1013, 1014, 1015, 1020, 1021) were not stored for a significant period of time and, therefore, a storage/charge voltage relationship is not apparent for these cell lots. Although the observed battery storage data may be helpful in future study of this subject, the effect of long-term storage and methods of storage on battery life and performance has not been fully investigated at this time.

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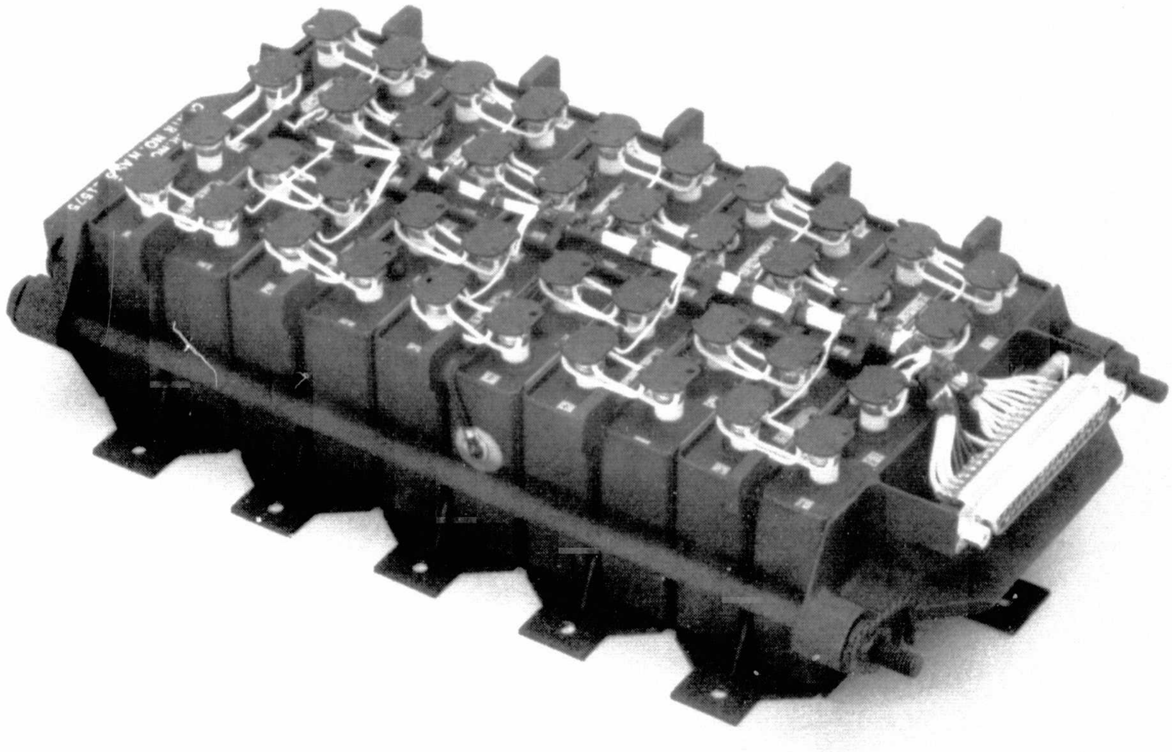

Figure 5-5. SMS/GOES Battery Assembly

Table 5-6. Battery Assembly Acceptance Test Matrix

Performance Parameters	Examination of product	Functional performance	Vibration – sinusoidal	Vibration – random	Post vibration performance	Thermal vacuum	Post thermal vacuum
Thermistor performance		X				X	X
Charge retention							X
Pulse load							X
Thermal vacuum						X	
Temperature performance						X	
Full charge voltage					X		
Visual inspection for damage			X	X		X	
Discharge voltage stability			X	X			
Vibration, random				X			
Vibration, sinusoidal			X				
Electrolyte leakage		X					X
High temperature capacity		X					
Low temperature capacity		X					
Capacity		X			X		X
Reconditioning		X					
Insulation resistance		X			X		X
Identification	X						
Dimension	X						
Weight	X						
Interchangeability	X						
Construction	X						
Workmanship	X						

Table 5-7. SMS/GOES Test Data

TEST/PARAGRAPH	REQUIREMENT	DATA 1005	DATA 1006	DATA 1007	DATA 1008	DATA 1009	DATA 1010
Examination of Product/ 4.5.1		OK					
Workmanship/3.1.6	MIL-STD-454 Reqt. 9	OK	OK	OK	OK	OK	OK
Construction/3.1.7	SD-212066	OK	OK	OK	OK	OK	OK
Interchangeability 3.1.4	Dwg 213827	OK	OK	OK	OK	OK	OK
Weight/3.1.1	7.9 lbs	7.44 lbs	7.41 lbs	7.42 lbs	7.35 lbs	7.36 lbs	7.64 lbs
Dimension/3.1	Dwgs 213827 & 211103	OK	OK	OK	OK	OK	OK
Functional Performance/4.5.2							
Insulation Resistance/ 4.5.2.1	10 Mohms at +100V (+10, -0)	10^3 M	10^3 M	10^3 M	10^2 M	10^2 M	10^2 M
Reconditioning/4.5.2.2	3.0 AH	4.20 AH	4.15 AH	3.82 AH	3.32 AH	3.26 AH	3.66 AH
Capacity/4.5.2.3	3.0 AH	4.04 AH	3.96 AH	4.00 AH	3.95 AH	3.84 AH	4.28 AH
Low Temp Capacity/4.5.2.5	2.25 AH	3.34 AH	3.39 AH	3.77 AH	3.77 AH	3.81 AH	3.79 AH
High Temp Capacity/4.5.2.5	1.50 AH	3.12 AH	3.04 AH	3.30 AH	2.81 AH	2.55 AH	3.45 AH
Thermistor Performance/ 4.5.2.6 - ±2% of calibration curve value	+2% @ +33°C	11020	11,000	10925	11001	11100	11104
	+20°C	17755	17,650	16895	17700	17870	18291
	+2°C	39500	38,800	39110	40160	41280	40241
Electrolyte Leakage/4.5.2.7	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
Vibration/4.5.3							
Discharge Voltage Stability/4.5.3.2	±0.25V/min	0.13 V/min	0.16 V/min	0.14 V/min	0.13 V/min	0.16 V/min	0.20 V/min
Visual Inspection/4.5.3.3	No evidence	No evidence	No Evidence	No evidence	No evidence	No evidence	No Evidence
Post Vibration/4.5.4							
Capacity/4.5.4.1	3.0 AH	3.94 AH	3.87 AH	3.86 AH	3.32 AH	3.84 AH	3.90 AH
Full Charge Voltage/	30°C, 29.6V/Battery	28.53 V/Batt	28.48V/Batt.	28.33V/Batt	28.26 V/Batt	28.24 V/Batt	28.24 V/Batt.
	1.48V/Cell	1.44 V/Cell	1.43 V/Cell	1.43 V/Cell	1.422 V/Cell	1.420 V/Cell	1.420 V/Cell
	10°C, 30.8V/Battery	30.12 V/Batt	29.95V/Batt.	30.4 V/Batt	29.49 V/Batt	29.31 V/Batt	28.97 V/Batt.
	1.54/Cell	1.534 V/Cell	1.52 V/Cell	1.546V/Cell	1.496 V/Cell	1.480 V/Cell	1.463 V/Cell
Insulation Resistance/ 4.5.4.3	10 Mohms at +100V	10^3 M	10^3 M	10^3 M	10^2 M	10^2 M	10^2 M
Thermal Vacuum/4.5.5							
Temperature Performance/ 4.5.5.1	24.0V @ +33°C	26.02 V	26.00 V	25.93 V	25.67 V	25.65 V	25.67 V
	24.0V @ +20°C	25.29 V	25.26 V	25.21 V	25.43 V	25.39 V	25.48 V
	24.0V @ +2°C	26.32 V	26.30 V	26.30 V	25.58 V	25.60 V	26.00 V
Thermistor Performance/ 4.5.5.2	±2% of Calibration curve value.	33°C 10546	33°C 10733	33°C 10860	33°C 10646	33°C 10575	33°C 11254
		20°C 18550	20°C 18680	20°C 18460	20°C 17397	20°C 17472	20°C 17850
		2°C 44830	2°C 42940	2°C 40700	2°C 41430	2°C 41486	2°C 43430
Visual Inspection/4.5.5.3	No evidence	No evidence	No evidence	No evidence	No evidence	No evidence	No evidence
Post Thermal-Vacuum/4.5.6							
Capacity	3.0 AH	3.69 AH	3.64 AH	3.96 AH	3.75 AH	3.66 AH	4.02 AH
Pulse Load/4.5.6.2	18.5 V/Batt.	22.44 V	22.22 V	22.60 V	22.53 V	22.27 V	23.02 V
	0.7V/Cell Max.	N/A	N/A	1.164 V	1.161 V	1.164 V	1.185 V
	Min.	1.106 V	1.116V	1.106 V	1.110 V	1.086 V	1.141 V
Thermistor Performance/ 4.5.6.3	± 2% of Calibration curve value	33°C 11120	33°C 11032	33°C 10880	33°C 10602	33°C 10965	33°C 10908
		20°C 18015	20°C 17845	20°C 17419	20°C 18404	20°C 18800	20°C 17010
		2°C 39600	2°C 39400	2°C 39975	2°C 39690	2°C 40430	2°C 40897
Charge Retention/4.5.6.4	1.16V/Cell Max	1.197 V	1.231 V	1.206 V	1.241 V	1.238 V	1.288 V
	Min	0.952 V	0.940V	1.166 V	1.230 V	1.216 V	1.213 V
Insulation Resistance/4.5.6.5	10M @ +100V	10^3 M	10^3 V	10^3 M	10^2 M	10^2M	10 M
Electrolyte Leakage/4.5.6.6	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless

Table 5-7. SMS/GOES Test Data (Continued)

TEST/PARAGRAPH	REQUIREMENT	DATA 1011	DATA 1012	DATA 1013	DATA 1014	DATA 1015	DATA 1020
Examination of Product 4.5.1							
Workmanship	MIL-STD-454 Reqt. 9	OK	OK	OK	OK	OK	S/O 326
Construction/3.1.7	SD-212066	OK	OK	OK	OK	OK	S/O 326
Interchangeability/3.1.4	Dwg 213827	OK	OK	OK	OK	OK	S/O 326
Weight/3.1.1	7.9 lbs	7.64 lbs	7.62 lbs	7.49 lbs	7.49 lbs	7.49 lbs	7.53 lbs
Dimension/3.1	211103	OK	OK	OK	OK	OK	S/O 326
Functional Performance/4.5.2							
Insulation Resistance/ 4.5.2.1	10 Mohms at +100V (+10,-0)	10^3 M	10^3 M	10 M	10 M	10 M	100 M
Reconditioning/4.5.2.2	3.0 AH	3.95 AH	3.96 AH	3.93 AH	3.92 AH	3.93 AH	4.25 AH
Capacity/4.5.2.3	3.0 AH	4.26 AH	4.37 AH	4.23 AH	4.16 AH	4.19 AH	4.11 AH
Low Temp Capacity/4.5.2.5	2.25 AH	3.77 AH	3.86 AH	3.74 AH	3.54 AH	3.59 AH	3.68 AH
High Temp Capacity/4.5.2.5	1.50 AH	2.70 AH	2.79 AH	4.10 AH	4.01 AH	3.95 AH	4.11 AH
Thermistor Performance/ 4.5.2.6 - ±2% of calibration curve value	±2% @ +33°C +20°C +2°C	11527 17591 39650	11316 17432 40320	10825 17861 37860	10971 17654 37721	11235 18235 38646	11654 18229 41025
Electrolyte Leakage/4.5.2.7	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
Vibration/4.5.3							
Discharge Voltage Stability/4.5.3.2	± 0.25V/min	0.16 V/min	0.10 V/min	0.01 V/min	0.02 V/min	0.02 V/min	0.06 V/min
Visual Inspection/4.5.3.3	No evidence	No evidence	No evidence	No evidence	No evidence	No evidence	No evidence
Post Vibration/4.5.4							
Capacity/4.5.4.1	3.0 AH	4.20 AH	4.24 AH	4.23 AH	4.17 AH	4.19 AH	4.11 AH
Full Charge Voltage/4.5.4.2	30°C, 29.6V/Batt 1.48V/Cell 10°C, 30.8V/Batt 1.54V/Cell	28.29V/Batt 1.419V/Cell 29.67V/Batt. 1.490V/Cell	28.34V/Batt. 1.423V/Cell 29.86V/Batt. 1.505V/Cell	28.6V/Batt. 1.44V/Cell 30.4V/Batt. 1.53V/Cell	28.8V/Batt 1.45V/Cell 30.5V/Batt 1.53V/Cell	28.7V/Batt. 1.44V/Cell 30.4V/Batt. 1.53V/Cell	28.98 V/Batt. 1.452 V/Cell 30.24 V/Batt. 1.549 V/Cell
Insulation Resistance/4.5.4.3	10 Mohms @ +100V	10^3 M	10^3 M	10 M	10 M	10 M	10^2 M
Thermal Vacuum/4.5.5							
Temperature Performance/ 4.5.5.1	24.0V @ +33°C 24.0V @ +20°C 24.0V @ +2°C	25.77V 25.49V 25.90 V	25.74 V 25.46 V 25.89 V	25.4 V 25.3 V 25.6 V	25.4 V 25.3 V 25.6 V	25.4 V 25.3 V 25.6 V	25.92 V 25.51 V 26.02 V
Thermistor Performance/4.5.5.2	±2% of Calibration curve value	33°C 10488 20°C 18030 2°C 38360	33°C 10533 20°C 18120 2°C 38640	33°C 10348 20°C 18928 2°C 40230	33°C 10445 20°C 18952 2°C 39912	33°C 10346 20°C 19001 2°C 40410	33°C 11895 20°C 17346 2°C 37691
Visual Inspection/4.5.5.3	No evidence	No evidence	No evidence	No evidence	No evidence	No evidence	No evidence
Post Thermal-Vacuum/4.5.6							
Capacity/4.5.6.1	3.0 AH	3.90 AH	3.96 AH	4.23 AH	4.05 AH	4.07 AH	4.02 AH
Pulse Load/4.5.6.2	18.5V/Batt	22.80 V	22.82 V	21.9 V	22.0 V	22.0 V	22.52 V
	0.7V/Cell Max.	1.162 V	1.164 V	1.12 V	1.12 V	1.125 V	1.152 V
	Min.	1.124 V	1.125 V	1.09V	1.09 V	1.09 V	1.114 V
Thermistor Performance/ 4.5.6.3	±2% of Calibration curve value	33°C 10780 20°C 18326 2°C 38160	33°C 10576 20°C 17740 2°C 38600	33°C 11291 20°C 18145 2°C 41130	33°C 11360 20°C 18123 2°C 40800	33°C 11276 20°C 18018 2°C 40730	33°C 11776 20°C 18085 2°C 40040
Charge Retention/4.5.6.4	1.16V/Cell Max	1.242 V	1.235 V	1.21 V	1.20 V	1.21 V	1.215 V
	Min	1.192 V	1.213 V	1.18 V	1.17 V	1.16 V	1.209 V
Insulation Resistance/ 4.5.6.5	10M @ +100V	10^3 M	10^3 M	10 M	10 M	10 M	10^2 M
Electrolyte Leakage/4.5.6.6	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless

Table 5-7. SMS/GOES Test Data (Continued)

TEST/PARAGRAPH	REQUIREMENT	DATA 1021
Examination of Product/ 4.5.1		
Workmanship/3.1.6	MIL-STD-454 Reqt. 9	S/O 329
Construction/3.1.7	SD-212066	S/O 329
Interchangeability/3.1.4	Dwg 213827	S/O 329
Weight/3.1.1	7.9 lbs	7.53 lbs
Dimension/3.1	Dwgs 213827 &211103	S/O 329
Functional Performance/4.5.2		
Insulation Resistance/ 4 4.5.2.1	10 Mohms at +100V (+10,-0)	100 M
Reconditioning/4.5.2.2	3.0 AH	4.08 AH
Capacity/r.5.2.3	3.0 AH	4.11 AH
Low Temp Capacity/4.5.2.4	2.25 AH	3.75 AH
High Temp Capacity/4.5.2.5	1.50 AH	4.20 AH
Thermistor Performance/ 4.5.2.6 - ±2% of calibration curve value.	±2% @ +33°C	11635
	+20°C	18161
	+2°C	41210
Electrolyte Leakage/4.5.2.7	Colorless	Colorless
Vibration/4.5.3		
Discharge Voltage Stability/4.5.3.2	±0.25V/min	0.04 V/min
Visual Inspection/4.5.3.3	No evidence	No evidence
Post Vibration/4.5.4		
Capacity/4.5.4.1	3.0 AH	4.08 AH
Full Charge Voltage/ 4.5.4.2	30°C, 29.6V/Battery	28.92V/Batt.
	1.48V/Cell	1.456V/Cell
	10°C, 30.8V/Battery	30.55V/Batt
	1.54V/Cell	1.537V/Cell
Insulation Resistance/ 4.5.4.3	10 Mohms @ +100	10^2 M
Thermal Vacuum/4.5.5		
Temperature Performance/ 4.5.5.1	24.0V @ +33°C	25.92 V
	24.0V @ +20°C	25.52 V
	24.0V @ +2°C	25.90 V
Thermistor Performance/ 4.5.5.2	±2% of Calibration curve value	33°C 11838
		20°C 17118
		2°C 38490
Visual Inspection/4.5.5.3	No evidence	No evidence
Post Thermal-Vacuum/4.5.6		
Capacity/4.5.6.1	3.0 AH	4.04 AH
Pulse Load/4.5.6.2	18.5V/Batt	22.39 V
	0.7V/Cell	
	Max	1.141 V
	Min	1.098 V
Thermistor Performance/4. 4.5.6.3	±2% of Calibration curve value	33°C 11684
		20°C 18165
		2°C 38664
Charge Retention/4.5.6.4	1.16V/Cell	
	Max	1.217 V
	Min	1.207 V
Insulation Resistance/4.5.6.5	10M @ +100V	10^2 M
Electrolyte Leakage/4.5.6.6	Colorless	Colorless

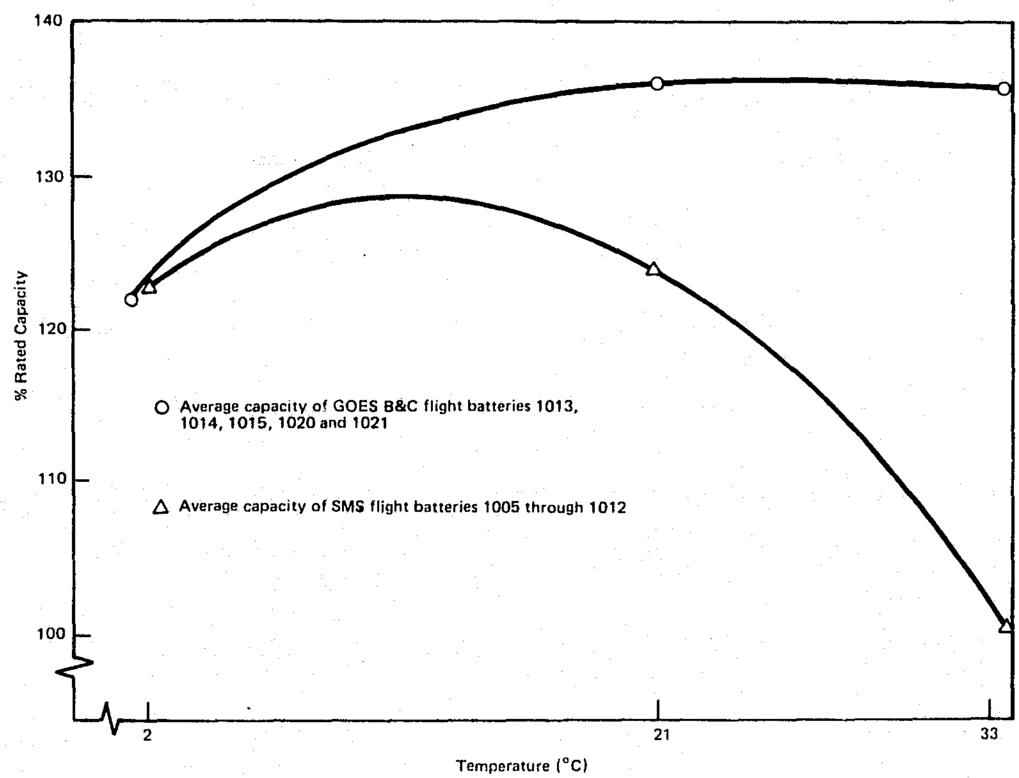

Figure 5-6. SMS/GOES Battery Capacity vs Temperature

Table 5-8. SMS/GOES Maximum Battery Charge Voltage Characteristics During Low Temperature Battery Capacity Tests

Cell Mfg Lot	Battery S/N	Charge Current (mA)*	Maximum Battery Voltage (V)	Maximum Cell Voltage (V)
6	1005	128	31.06	1.574
6	1006	131	30.91	1.579
5	1007	150	30.64	1.550
7	1008	141	30.82	1.563
7	1009	140	30.90	1.567
8	1010	131	30.89	1.573
8	1011	150	30.85	1.577
8	1012	150	30.99	1.561
10	1013	132	30.83	1.554
10	1014	150	30.76	1.559
10	1015	150	30.66	1.553
12	1020	150	30.78	1.548
12	1021	141	30.77	1.560

*Charge current limited by charging power supply source to allow a maximum voltage of 31.0 volts, nominal, at the battery terminals.

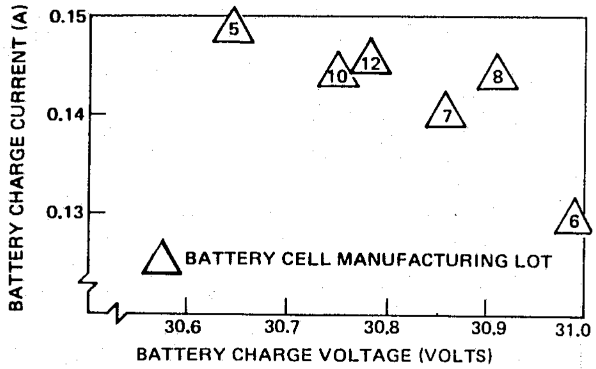

Figure 5-7. Battery Charge Voltage vs Current (Average Data Shown for Indicated Cell Manufacturing Lots)

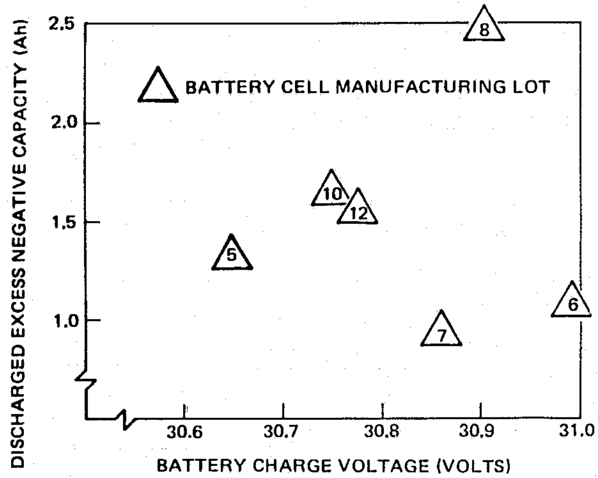

Figure 5-8. Battery Charge Voltage vs Excess Negatives (Average Data Shown for Indicated Cell Manufacturing Lots)

Table 5-9. SMS/GOES Battery Activation Test Results After Storage

BATTERY S/N	A/T DATE	ACTIVATION DATE	STORAGE PERIOD (MO)	CAPACITY (Ah)	PEAK VOLTAGE (V)
1005	8/73	8/75	24	4.04	29.92
1006	8/73	4/74	8	4.08	29.54
1007	9/73	4/74	7	4.05	29.50
1008	2/74	12/74	10	3.81	29.42
1009	2/74	8/75	18	4.25	29.42
1010	8/74	8/75	12	4.20	29.45
1011	8/74	12/74	4	4.07	29.06
1012	8/74	8/75	12	4.29	29.46
1013	2/76	3/77	13	4.13	29.87
1014	2/76	3/77	13	4.14	29.80
1015	2/76	3/77	13	4.14	29.87
1020	2/77	N/A*	N/A*	N/A*	N/A*
1021	2/77	4/77	2	4.19	29.61

*Not activated

SECTION 6

ORBITAL MISSION PERFORMANCE AND LIFE TEST

FLIGHT BATTERY DATA SUMMARY

Flight battery equinox season data are presented for the SMS-A and SMS-B satellites, launched on 17 May 1974 and 16 February 1975, respectively, and for GOES-A, launched on 16 October 1975. Data were not available for GOES-B, launched on 16 June 1977. GOES-C is scheduled to be launched in 1978.

Battery Operation

SMS/GOES batteries have a 5-year mission life based on a maximum 60 percent depth of discharge (DOD) at equinox. Battery charging is normally performed at the intermediate (2/3) rate during equinox operation and (1/3) rate during solstice periods. The maximum thermal design limit of 28°C has been met on all satellites for battery overcharge periods. Minimum battery temperatures ranging from -1 to +2°C have occurred immediately following eclipse emergence, prior to entering overcharge. These temperatures compare closely with thermal predictions of Figure 2-5. Data obtained from the National Oceanographic and Atmospheric Administration (NOAA) for battery operation during eclipse for SMS-A, SMS-B and GOES-A through autumnal equinox 1976 are summarized in Figures 6-1 through 6-5.

SMS-A Batteries

Batteries on this satellite have completed seven equinox seasons since launch on 17 May 1974. SMS-A operational load requirements have resulted in a typical 55 percent battery DOD each day throughout the eclipse season, rather than being proportioned to the eclipse period profile, as shown in Figure 2-2. Battery power has been required during sunlight operation periods. Battery overcharge voltage values specified for this satellites were implemented for the intermediate (2/3) charge rate during equinox operation, as follows:

- 30.2 volts maximum for battery temperatures from 0 to 10°C
- 30.0 volts maximum for battery temperatures from 10 to 20°C
- 29.6 volts maximum for battery temperatures from 20 to 30°C

These limits were later modified for the convenience of ground control operators and the 30.0 volt limit for the 10 to 20°C range was increased to 30.2 volts for periods less than 30 minutes above 30.0 volts. Figures N-1 through N-6 (Appendix N) provided by NOAA show daily maximum and minimum battery voltage and temperature trends through the first four equinox and solstice periods.

SMS-B Batteries

Satellite power management has resulted in a typical 45 percent maximum battery DOD at equinox since launch on 16 February 1975. Additional satellite load requirements during solstice season have resulted in loads ranging from 1 to 38 percent DOD. Figures N-7 through N-10 (Appendix N) provided by NOAA show effects of this operation on daily maximum

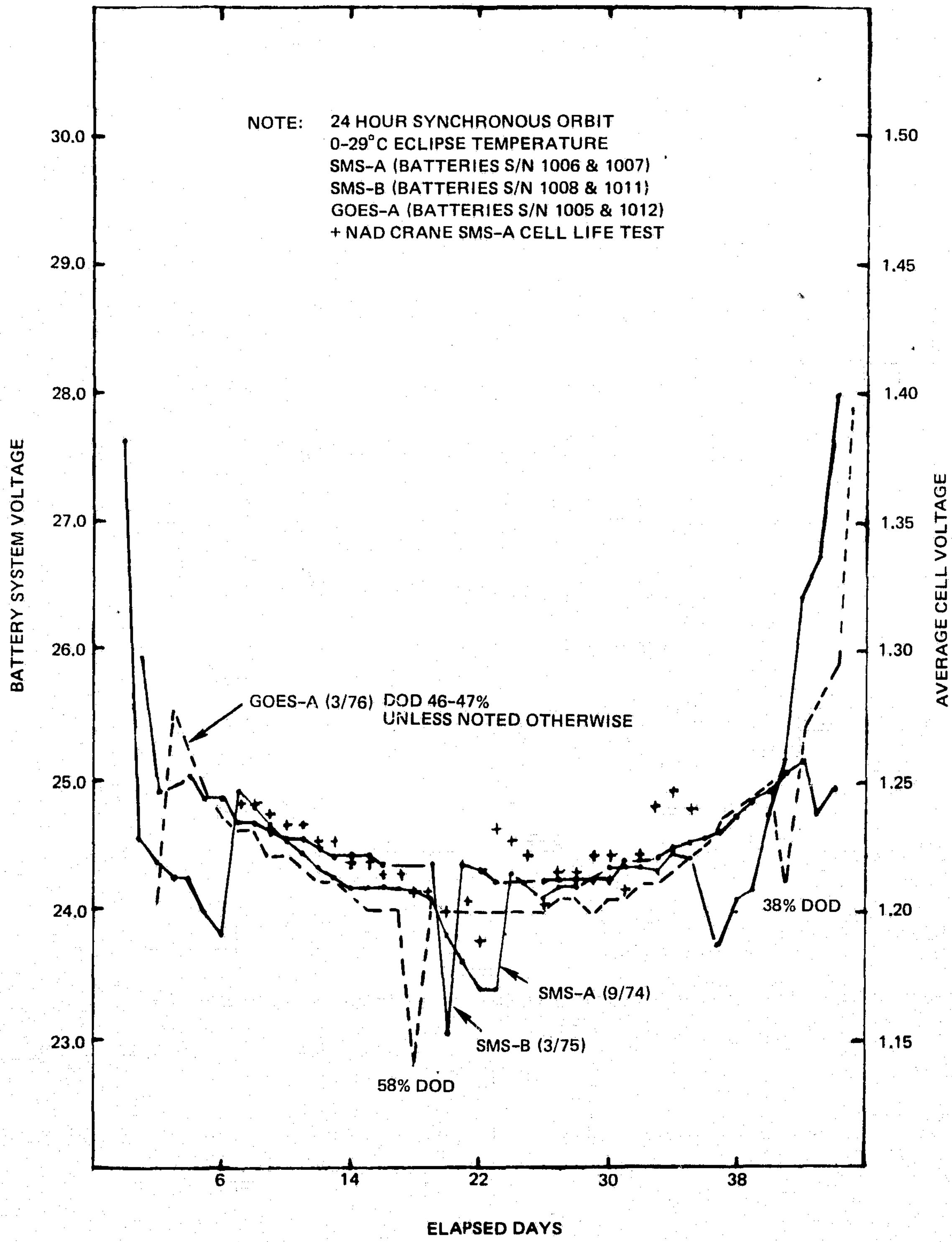

Figure 6-1. SMS/GOES Orbital Eclipse Season 1, Minimum Battery Discharge Voltage

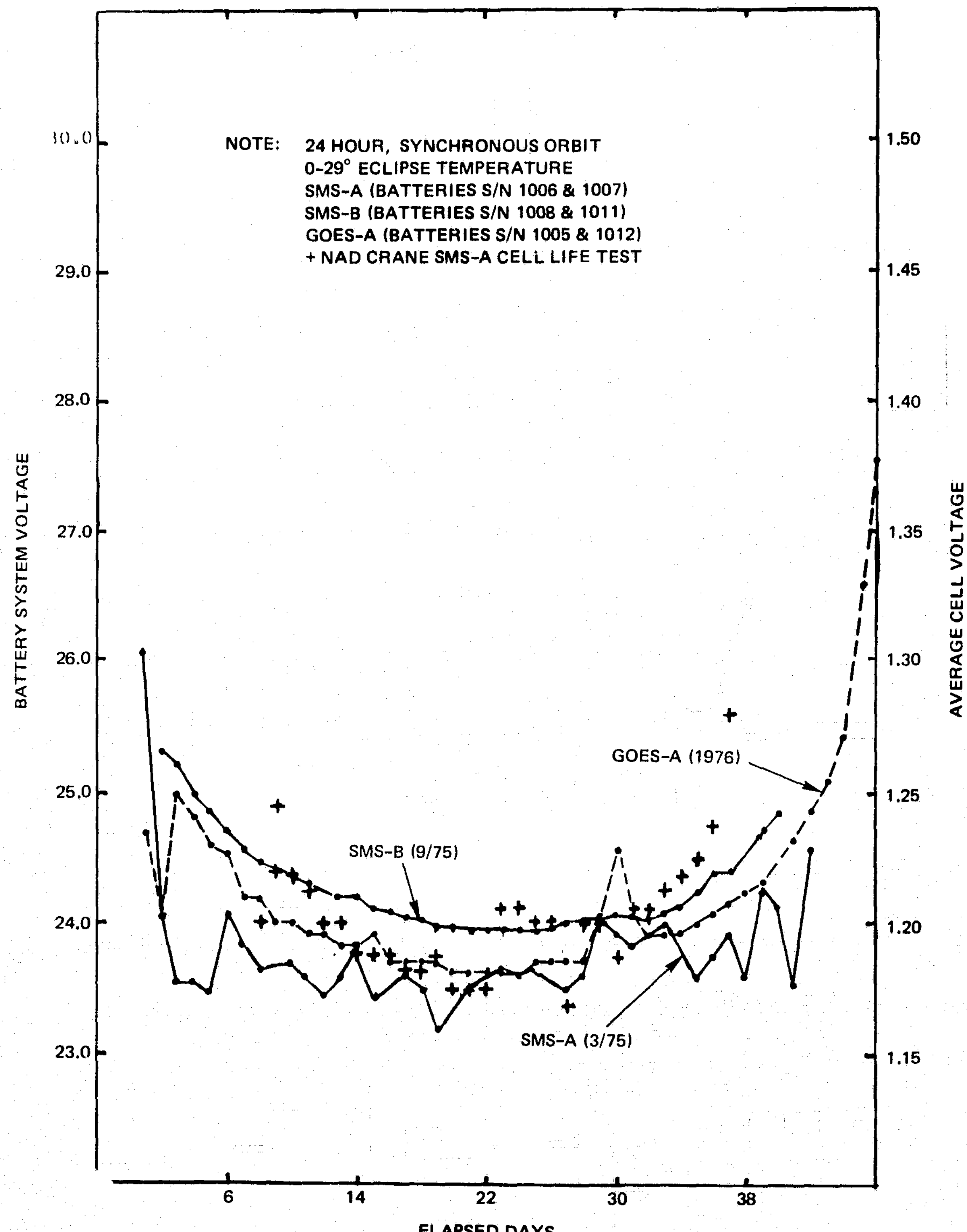

Figure 6-2. SMS/GOES Orbital Eclipse Season 2, Minimum Battery Discharge Voltage

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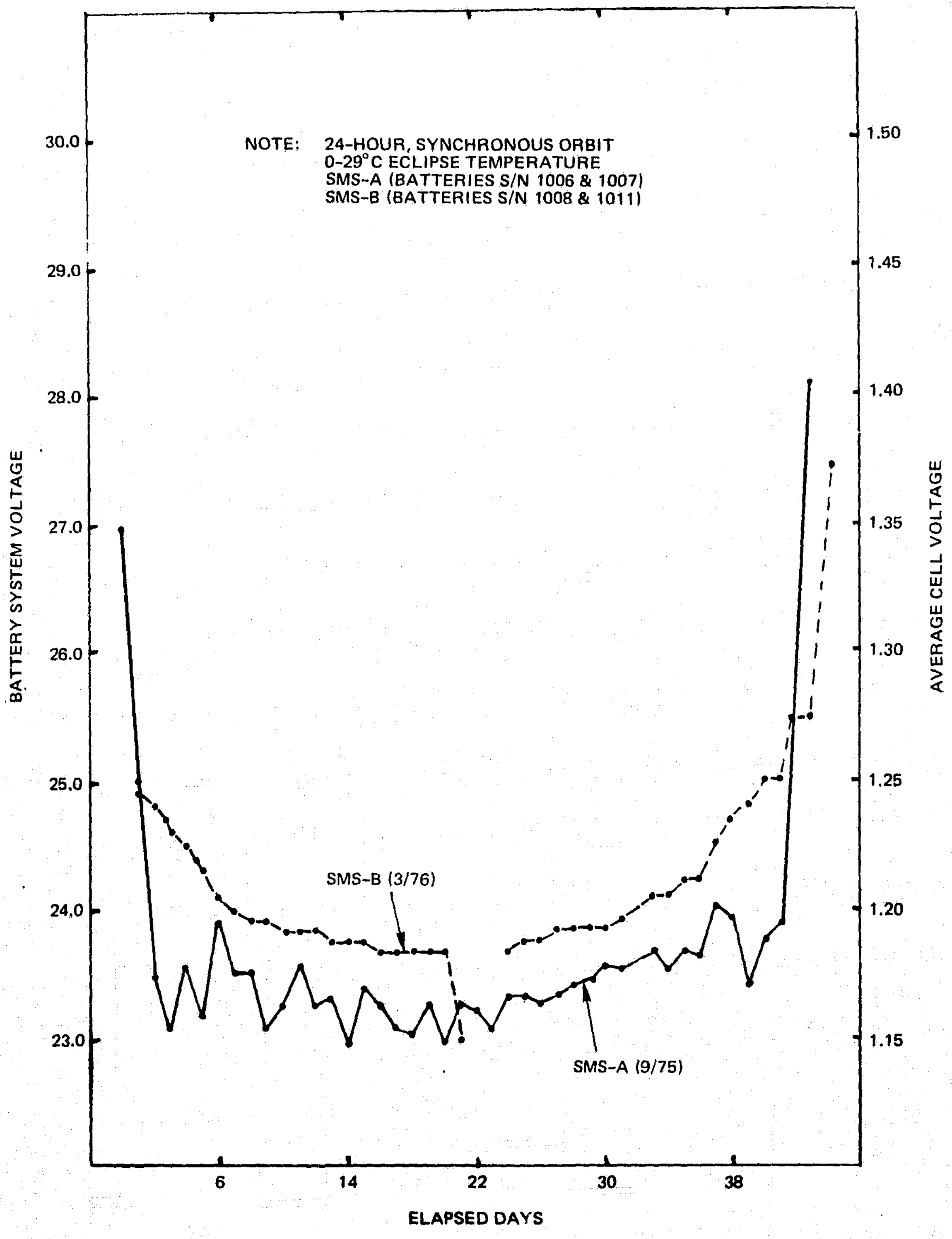

Figure 6-3. SMS/GOES Orbital Eclipse Season 3, Minimum Battery Discharge Voltage

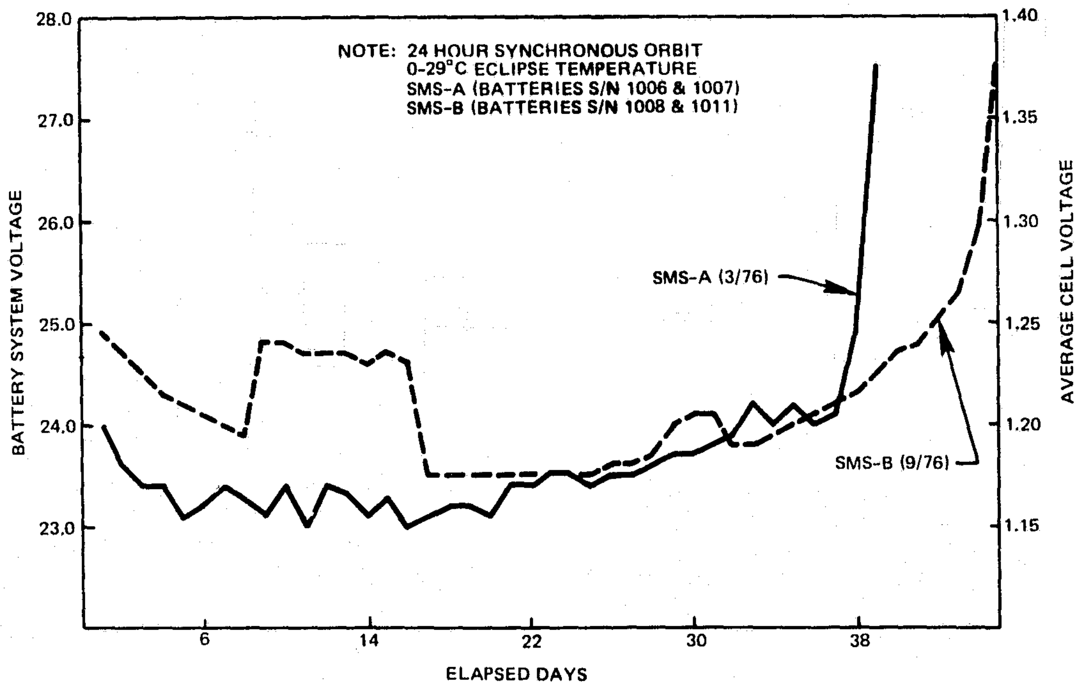

Figure 6-4. SMS/GOES Orbital Eclipse Season 4, Minimum Battery Discharge Voltage

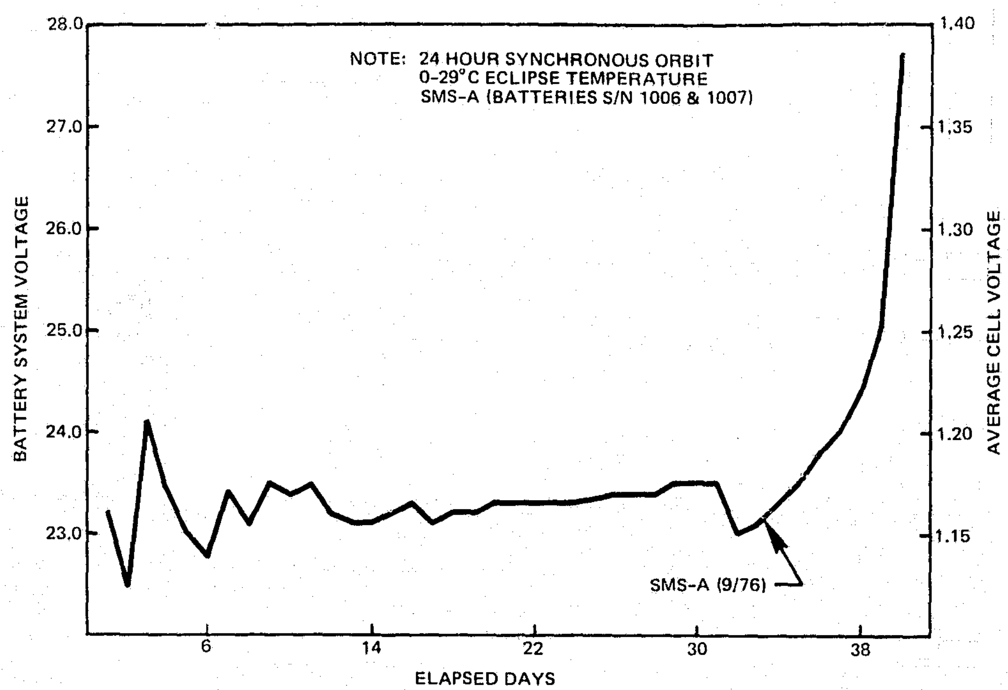

Figure 6-5. SMS/GOES Orbital Eclipse Season 5, Minimum Battery Discharge Voltage

and minimum battery voltages and temperatures. Because batteries on this satellite were assembled from two separate cell manufacturing lots, individual battery voltage characteristics vary for similar operating conditions. Variations in battery charge voltages are summarized in Table 6-1.

Table 6-1. SMS-B Maximum Battery Voltages Following Eclipse for 1/3, 2/3, and 3/3 Charge Rates

		Pre Eclipse	Eclipse				
J day		244	245	246	247	248	249
Eclipse day		-1	1	2	3	4	5
Charge rate		1/3	1/3	1/3	2/3	2/3	2/3
1975	Battery 1V	29.009	28.442	28.568	29.702	29.639	29.009
	Battery 2V	28.379	28.127	28.253	28.883	28.820	28.253
	Δv	-0.630	-0.315	-0.315	-0.819	-0.819	-0.756
J day		57	58	59	60	61	62
Eclipse day		-1	1	2	3	4	5
Charge rate		1/3	1/3	1/3	1/3	1/3	*3/3,1/3
1976	Battery 1V	27.749	28.127	28.253	28.631	28.568	29.324
	Battery 2V	27.812	28.316	27.245	27.245	27.560	28.379
	Δv	+0.063	+0.189	-1.008	-1.386	-1.008	-0.945

*Operator error, returned to 1/3 chg rate after, 2.5 hours
Source: W. Schedler, FACC

Data in this table show lower charge voltages early in the eclipse season for battery 2 (S/N 1011) with respect to battery 1 (S/N 1008). The autumnal equinox season for 1975 shown in this table began on J-Day 245 (Julian), while the vernal equinox season for 1976 started on J-Day 58. Since data shown for 1976 match the 1975 data, it was concluded that the lower charge voltages for battery 2 were characteristic of cell lot manufacturing differences. Battery 1 was assembled with cells from Lot 7 and battery 2 from Lot 8 cells. Similar lower voltages were also observed during the subsequent autumnal eclipse season on J-Day 268, as shown in Figure 6-6. End of charge voltage variations for battery 2 in this figure are due to changes in the battery charge rate. Figure 6-7 shows the battery temperature profiles for this corresponding day.

Although general battery eclipse power requirements for SMS-B do not exceed the 60 percent DOD equinox design limit, battery load sharing has been utilized during summer solstice operation. In order to document parametric characteristics of load sharing on battery recharge efficiency, special tests were conducted as described later in this section. These test results were used to establish operational constraints.

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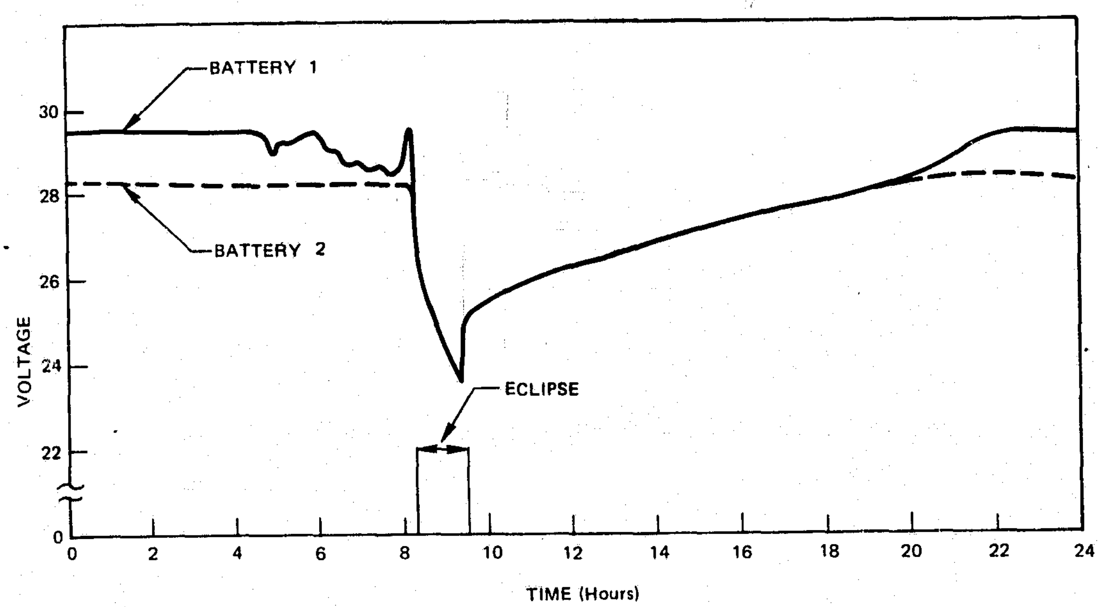

Figure 6-6. SMS-B Autumnal Eclipse J-Day 268 for 1976, Battery 1 (S/N 1008) and Battery 2 (S/N 1011) Voltages

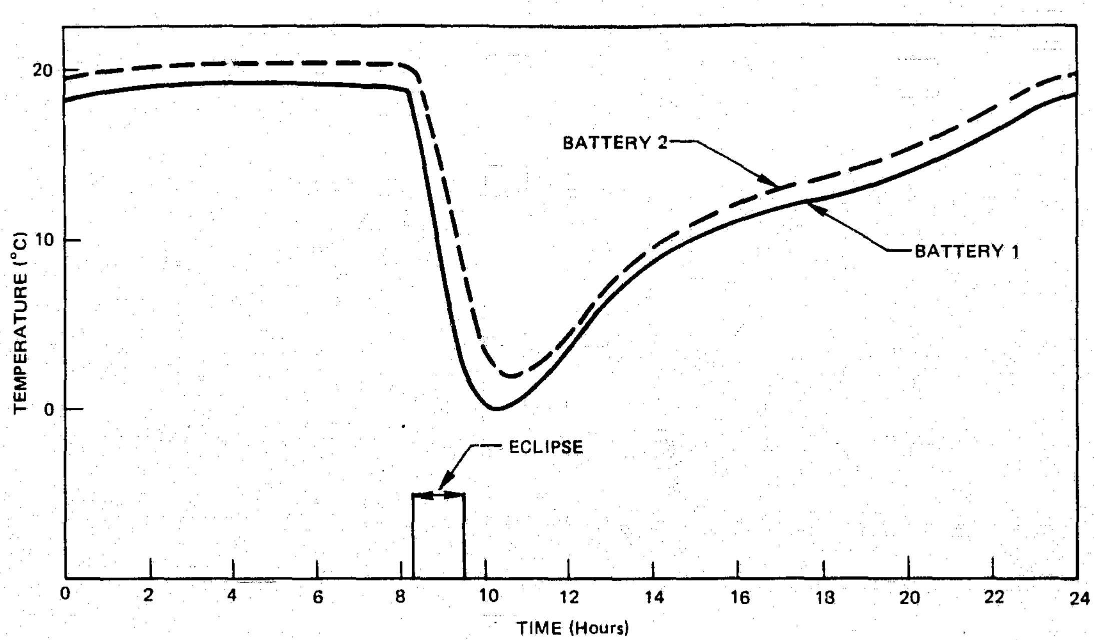

Figure 6-7. SMS-B Autumnal Eclipse J-Day 268 for 1976, Battery 1 (S/N 1008) and Battery 2 (S/N 1011) Temperatures

GOES-A Batteries

Batteries on this satellite have experienced four equinox seasons since launch on 16 October 1975. Battery 1 (S/N 1005) was assembled from Lot 6 cells similar to batteries used on SMS-A. Battery 2 (S/N 1012) was assembled with cells from Lot 8, which incorporated the highest negative electrode active material loading for the SMS/GOES Program. Figures N-11 through N-12 (Appendix N) provided by NOAA show daily maximum and minimum battery voltages and temperatures for the first two equinox and solstice periods. As with SMS-A and SMS-B, battery voltage variations with time during solstice operation are due to satellite power requirements occasionally exceeding the solar array capability. Figures 6-8 and 6-9 show relative differences in charging voltage and temperature characteristics for Lots 6 and 8 battery cells. Lot 6 cells for battery 1 (S/N 1005) have peak voltage characteristics similar to SMS-A batteries. Battery 2 (S/N 1012) voltage data for Lot 8 cells compare closely with data shown in Figure 6-6 for SMS-B battery 2 (S/N 1011) which also has Lot 8 cells.

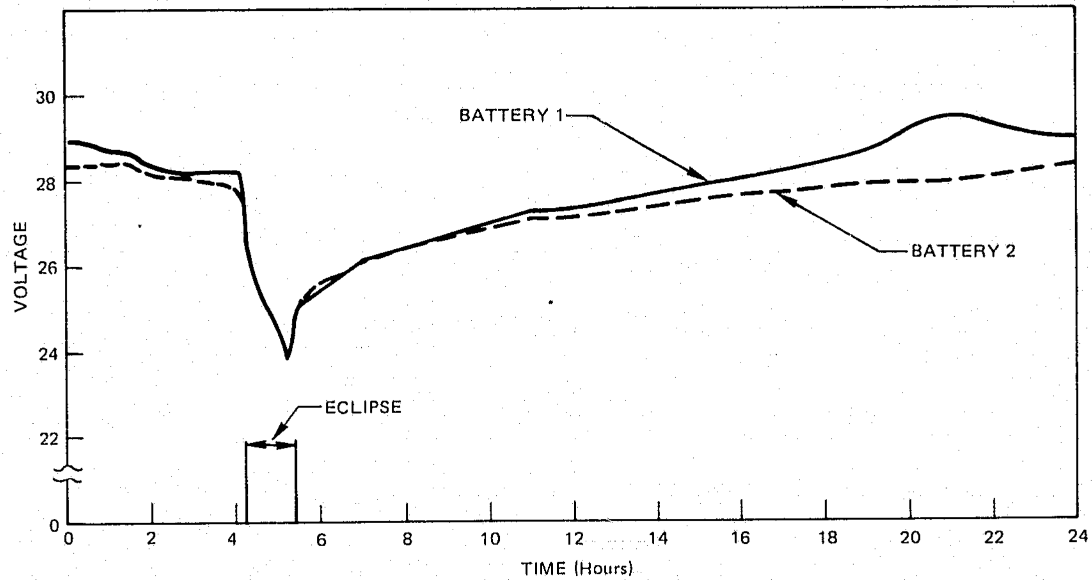

Figure 6-8. GOES-A Vernal Eclipse J-Day 268 for 1976, Battery 1 (S/N 1005) and Battery 2 (S/N 1012) Voltages

LIFE TEST AND FLIGHT DATA EVALUATION

NASA-NWSC Testing

Two test groups representing cells from Lots 6, 10, and 12 were placed on real-time synchronous orbit cycling at the Naval Weapons Support Center (NWSC) located in Crane, Indiana. The purpose of the tests was to verify performance and life characteristics to aid in establishing orbital battery operation procedures. Battery cells in each test group were subjected to tests summarized in Figure 6-10. Detailed discussion of the results of these tests follows.

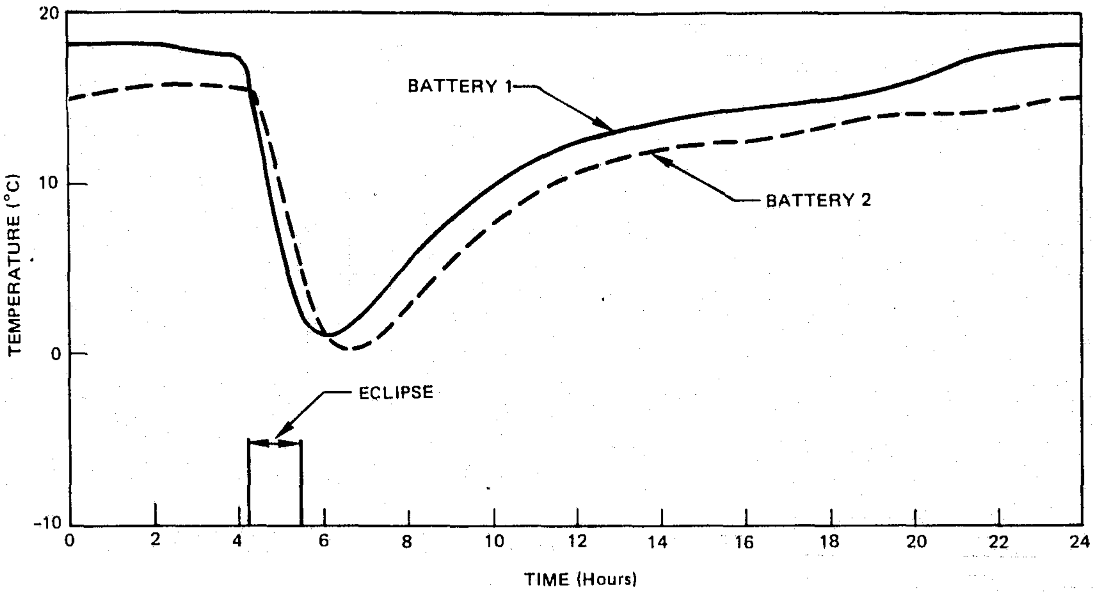

Figure 6-9. GOES-A Autumnal Eclipse J-Day 268 for 1976, Battery 1 (S/N 1005) and Battery 2 (S/N 1012) Temperatures

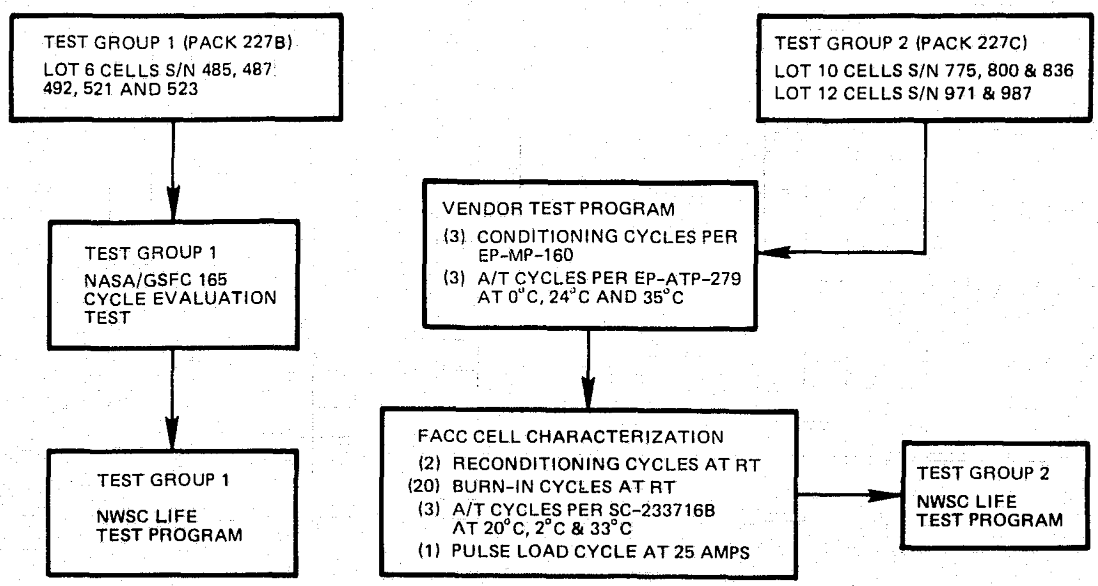

Figure 6-10. Packs 227B and 227C Chronological Test Sequence

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a. Lot 6 Cell Pack 227B. Cells in this test group were not screened at FACC, but were subjected to 165 cycles at GSFC, as summarized in Table 6-2. Although cell capacities remained stable during these tests, an increase in cell charging voltages and overcharge pressures with cycling was noted at the lower test temperatures as summarized in Table 6-3. One cell, S/N 521, had high overcharge voltage at low temperatures during the initial tests. In general, cell overcharge pressures in the temperature range of 20 to 35°C tended to decrease with cycle life. Upon completion of the 165-cycle characterization tests (the equivalent of 2 years of synchronous orbit cycling), this group was subjected to real-time synchronous orbit cycle tests at 20°C, as follows:

- 140-day sunlight simulation with battery state of charge maintained at 0.075 amp.
- 42-day eclipse simulation with battery discharge at 1.50 amp rate varying from 12 to 72 minutes maximum (except for 21st cycle during which a capacity measurement is made). Recharge following eclipse was at 0.15 amp for duration of 24-hour period remaining after eclipse.

Cell capacity and end-of-discharge voltage test results for the first four eclipse seasons are summarized in Table 6-4. It should be noted that the cells had an abbreviated 2-month trickle charge period prior to start of the initial eclipse season.

Cell S/N 523 was the limiting cell in the pack, as of the fourth season, and was delivering 73 percent of rated capacity. Figures N-13 through N-17 (Appendix N) summarize cell discharge voltage and capacity characteristics for the first four eclipse seasons, including the pre-eclipse cycle discharge at a 1.50 amp rate. Average end-of-charge voltage during the middle of Season 1 was 1.423 volts. Corresponding voltages for Seasons 2 and 3 were 1.413 and 1.404 volts, respectively. A decreased charging voltage trend similar to GSFC test results was also observed. End-of-charge pressures during these periods ranged from 0 to 103.4×10^{-3} N/mm^2 (0 to 15 lb/in^2).

b. Lots 10 and 12 Cell Pack 227C. These cells were subjected to screening acceptance tests at FACC prior to NWSC synchronous orbit life cycle tests. The pack is representative of cells used in assembly of GOES-B and -C batteries S/N 1013, 1014, 1015, 1020, and 1021. The cells began life cycling with the first eclipse season as previously described for Pack 227B.

Charge rate for the sunlight period was maintained at 0.085 amp for this pack. Recharge following eclipse was performed at 0.15 amp. Cell pack capacity and end-of-discharge voltage test results for the first eclipse season are summarized in Table 6-5.

Figures N-18 through N-20 (Appendix N) summarize cell voltage characteristics for the first eclipse season, including the precharge cycle discharge.

FACC Life Test

Accelerated synchronous orbit life cycle tests were conducted at room ambient conditions on cells from manufacturing Lots 1, 5, 6, 7, and 8 for a total of nine eclipse seasons. The accelerated cycle consisted of a 1.5 ampere discharge for 1.2 hours and a 0.15 ampere charge for 22.8 hours. The test group included engineering development cells and cells which had not been subjected to screening tests. Test and manufacturing background of these cells is included in Table 6-6 and Appendix G. The first 12 cells listed in this table were reconditioned

Table 6-2. Lot 6 Cell Pack 227B, GSFC Chronological Test Summary

Test Sequence Number	Type Test	No. of Cycles in Test Condition	Temp (°C)	Charge Rate (A)	Charge Time (hours)	EOC[b] Ah_{IN}	EOC[b] Avg Volts	Avg Pressure N/cm^2	Avg Pressure lb/in^2	EOD[c] Avg Volts	EOD[c] Capacity Ah_{OUT}	Comments
1	Reconditioning	1	20	.150	48	7.19	1.45	4.93	34		4.11	
2	Capacity	1	20	.3	17.5	5.25	1.48	4.64	32		4.04	
3	Voltage recovery	1	20	O.C.V	31		1.178	0.44	3			
4	Capacity	1	35	.3	19	5.67	1.40	12.62	87		3.33	
5	Ovrchg/Cap	1	0	.15	64	9.6	1.55	4.06	28		3.62	Cell No. 4 high voltage 1.604V
6	Chg efficiency	1	20	.3	10	3.0	1.40	2.18	15		2.045	
7	Capacity (repeat no. 2)	1	20	.3	17.5	5.25	1.47	4.06	28		3.981	
8	Chg eff (repeat no. 6)	1	20	.3	10	3.08	1.40	3.34	23		2.69	87% Eff.
9	Chg efficiency	1	20	.15	20	3.03	1.40	4.06	28		2.31	76% Eff.
10	Chg efficiency	1	20	.1	30	3.00	1.395	5.22	36		2.12	70% Eff.
11	Chg efficiency	1	20	.075	40	3.02	1.39	7.40	51		1.97	65% Eff.
12	Precycling chg	1	20	.3	17	5.094						
13	Cycling	7	20	.3	22.8	6.855	1.43	5.22	36	1.23	1.725	
14	Cycling	7	20	.15	22.8	3.418	1.41	5.66	39	1.21	1.757	
15	Capacity discharge	1	20								3.71	
16	Precycling chg	1	20/0[a]	.3/.15[a]		5.42						
17	Cycling	14	0	.15	22.8	3.43	1.51	3.77	26	1.22	1.74	
18	Capacity discharge	1	0								3.745	
19	Precycling chg	1	20/35	.3/.15/.075		11.78						
20	Cycling	7	35	.3	22.8	6.851	1.38	8.99	62	1.21	1.73	
21	Cycling	7	35	.15	22.8	3.42	1.37	8.56	59	1.17	1.74	
22	Capacity discharge	1	35								2.234	
23	Precycling chg	1	20	.3	17.5	5.277	1.45	2.61	18			
24	Cycling	7	20	.1	22.8	2.27	1.40	5.95	41	1.19	1.74	
25	Capacity discharge	1	20								2.77	
26	Capacity	1	35/25	.3		6.22					4.05	Temperature chamber malfunction
27	Capacity	1	35	.3	24	7.16	1.41	11.75	81		3.67	
28	Ovrchg/capacity	1	0	.15/.05/.15 (a)	66	7.58	1.65	5.66	39		3.61	Cells hit 1.53 V/cell clamp. Reading taken after clamp was removed

Table 6-2. Lot 6 Cell Pack 227B, GSFC Chronological Test Summary (Continued)

Test Sequence Number	Type Test	No. of Cycles in Test Condition	Temp (°C)	Charge Rate (A)	Charge Time (hours)	EOC[(b)] Ah_{IN}	EOC[(b)] Avg Volts	Avg Pressure N/cm²	Avg Pressure lb/in²	EOD[(c)] Avg Volts	EOD[(c)] Capacity Ah_{OUT}	Comments
29	Ovrchg/capacity	1	35	.3/.2	27.5	6.83	1.38	13.05	90		3.53	
30	Precycling charge	1	20	.3/.15		5.48						
31	Cycling	2	10	.15	22.8	3.42	1.57	4.21	29	1.24	1.72	Cell No. 4 high EOC 1.606 V
32	Cycling	6	20	.15	22.8	3.42	1.47	2.90	20	1.22	1.72	Cell No. 4 high EOC 1.553 V
33	Cycling	15	15	.15	22.8	3.43	1.46	2.32	16	1.21	1.75	Cell No. 4 low EOC voltage (1.415 volts)
34	Cycling	3	10	.1	22.8	2.26	1.47	4.35	30	1.19	1.76	Cell No. 4 high EOC voltage 1.567 V
35	Cycling	14	10	.15	22.8	3.41	1.54	4.79	33	1.20	1.76	Cell No. 4 low EOC voltage 1.432 V
36	Cycling	2	10	.085	22.8	1.94	1.42	4.21	29	1.19	1.76	
37	Cycling	7	5	.085	22.8	1.94	1.48	2.90	20	1.18	1.79	Cell No. 4 high EOC voltage 1.598 V
38	Cycling/Cap	1	5	.15/.085	22.8	3.186	1.51	7.25	50		3.75	
39	Precycling charge	1	24/10	.31/.15	20.5	5.53	1.47	1.60	11			
40	Cycling	14	10	.15	22.8	3.40	1.46	2.03	14	1.21	1.82	
41	Capacity	1	10								3.83	
42	Charge	1	10	.3/.046		2.67	1.38	1.02	7			
43	Cycling (up)	4	10	.086	22.8	1.96	1.40	1.16	8	1.04	1.80	Cannot maintain low state of charge at C/35 rate
44	Cycling (up)	22	10	.1	22.8	2.25	1.42	2.61	18	1.14	1.[illegible]2	
45	Capacity	1	10								2.39	
46	Overchg/Capacity	1	0	.15/.11	43.5	6.06	1.55	10.73	74		3.21	Cells hit voltage clamp
47	Overchg/Capacity	1	35	.3	20	6.03	1.42	4.35	30		3.68	
48	Capacity	1	20	.3	19	5.75	1.54	2.32	16			Cell No. 4 high voltage 1.62 V
49	Voltage recovery		24	O.C.V.	24		1.24	1.16	8			

Notes: (a) Start/end of test
(b) Ah, Avg Volts, and Avg Pressures are last cycle of test condition
(c) All discharges are at 1.5 A for 1.2 hours (average volts listed or 1.5 A to an average of 1.0 V/cell (capacity check)

Table 6-3. Lot 6 Cell Pack 227B, GSFC Pre- and Post-Cycling Test Data Summary

Test		Cell 1 (S/N 485)		Cell 2 (S/N 487)		Cell 3 (S/N 492)		Cell 4 (S/N 521)		Cell 5 (S/N 523)		Capacity
		Volts	N/cm^2 (lb/in^2)	Volts	N/cm^2 (lb/in^2)	Volts	N/cm^2 (lb/in^2)	Volts	N/cm^2 (lb/in^2)	Volts	N/cm^2 (lb/in^2)	Ah
20°C capacity	pre-cycling	1.475	4.21 (29)	1.480	5.37 (37)	1.479	4.35 (30)	1.480	3.92 (27)	1.480	5.08 (35)	4.04
C/10 charge	post-cycling	1.514	2.03 (14)	1.532	2.47 (17)	1.532	1.45 (10)	1.620	3.63 (25)	1.515	2.18 (15)	3.96
35°C capacity	pre-cycling	1.404	11.17 (77)	1.402	13.34 (92)	1.400	12.18 (89)	1.409	11.02 (76)	1.404	14.94 (103)	3.33
C/10 charge	post-cycling	1.422	4.06 (28)	1.419	4.21 (29)	1.414	3.48 (24)	1.427	6.09 (42)	1.416	4.06 (28)	3.68
0°C capacity	pre-cycling	1.536	2.03 (14)	1.545	3.05 (21)	1.553	4.06 (28)	1.604	5.80 (40)	1.519	5.51 (38)	3.62
C/20 charge	post-cycling*	1.559	9.43 (65)	1.540	8.85 (61)	1.546	9.28 (64)	1.582	17.40 (120)	1.545	8.70 (60)	3.21

*Voltage was clamped at 1.54 V/cell; at end of charge current was 0.11 A.

Table 6-4. Pack 227B Mid-Season Capacity Measurements

	End of Discharge Voltage					Ah Capacity
	Cell 1 (S/N 485)	Cell 2 (S/N 487)	Cell 3 (S/N 492)	Cell 4 (S/N 521)	Cell 5 (S/N 523)	
Pre-eclipse*	1.050	0.848	0.982	1.162	0.961	3.98
Season 1	0.679	0.414	0.605	0.441	0.581	4.20
Season 2	0.767	0.590	0.789	0.474	0.632	4.06
Season 3	0.852	0.684	0.819	0.573	0.441	3.65
Season 4	1.068	0.924	1.018	1.168	0.445	2.18

*Test performed after 165 cycles at GSFC as summarized in Table 6-2.

Table 6-5. Cell Capacity and End-of-Discharge Voltages for Pack 227C

	End of Discharge Voltage					Ah Capacity
	Cell 1 (S/N 775)	Cell 2 (S/N 971)	Cell 3 (S/N 800)	Cell 4 (S/N 987)	Cell 5 (S/N 836)	
Pre-eclipse*	1.012	0.996	0.923	0.871	0.875	4.23
Season 1	0.420	—	—	—	—	4.17
Season 2	TBD	TBD	—	—	—	TBD
Season 3	TBD	—	—	—	—	TBD
Season 4	TBD	TBD	TBD	—	—	TBD

*Test performed after reconditioning at NWSC following screening at WDL.

and started on life test in June 1974. After the first eclipse season was completed, 10 cells were added to the test group. Cells were discharged at 1.50 amp and recharged at 0.15 amp. Upon completion of the third eclipse season, a capacity check was made on cells S/N 12, 20, 403, 511, 540, 593, and 620. Cells S/N 706, 697, and 619 (which had completed two seasons) were also subjected to capacity measurements. Table 6-7 compares post-screening test burn-in capacities with capacities measured during and after the eclipse season life test. Cells S/N 403, 511, and 596 were subsequently subjected to the load sharing test described later in this section. Table 6-8 summarizes minimum cell voltages at equinox for the nine eclipse seasons.

Lot 7 cells and Lot 8 cells exhibited more capacity degradation than cells from Lots 5 and 6. Lot 1 cells that exhibited the most capacity degradation had been used in the engineering

development tests. This capacity degradation coupled with initial charge voltage peaking suggests a marginal quantity of electrolyte in the separator for Lot 7 and 8 cells, as previously discussed in Section 5.

FACC BATTERY CHARGE EFFICIENCY TESTS

Battery cell charge efficiency tests were performed for summer solstice season operating conditions when battery load sharing is required. Test parameters included charge rate, discharge rate, temperature, operating time, and battery state of charge. Twenty-three cells from manufacturing Lots 5, 6, 7, 10, and 12 were selected for this experiment. Short term (matrix) load sharing tests were conducted for cell operating temperatures of 10, 20, and 25°C, in accordance with conditions summarized in Table 6-9 and Appendix N. An extended 3-1/2 month orbital load sharing test was performed at 25°C for a calculated charge efficiency of 86 percent.

Test cells consisted of 20 Lot 10 and 12 cells screened per Procedure SC-213728 (included in Appendix I) and three engineering life test cells from Lots 5, 6, and 7. Initial testing was performed on the 20 Lot 10 and 12 cells for a calculated recharge efficiency of 92 percent at 10 and 25°C. The cells were removed from shorted storage, reconditioned, and tested for capacity at 20°C, per Procedure SC-213728. Charging voltages ranging from 1.502 to 1.536 occurred during initial capacity tests, as summarized in Appendix O for Test 6. The cells were recharged and subjected to a 168 hour square wave pulse load sharing test at 10°C. The pulse consisted of a 106 mA charge for 410 ms and a 200 mA discharge for 200 ms. Recharge efficiency for this test is calculated per Table 6-9.

Table 6-6. FACC Accelerated Life Test Cell Background

Test Position	Cell S/N	Mfg Lot	Previous Test History and Other Comments
1	11	1	EM Cell Development Tests
2	12	1	EM Cell Development Tests
3	20	1	Not screened at WDL
4	403	5	Screened at WDL (1.58 V peak at LT)*
5	412	5	Screened at WDL (1.53 V peak at LT)
6	488	6	Screened at WDL (1.54 V peak at LT)
7	511	6	Screened at WDL (1.61 V peak at LT)*
8	540	7	Screened at WDL (1.59 V peak at LT)
9	545	7	Screened at WDL (reversed during test)
10	547	7	Screened at WDL (1.56 V peak at LT)
11	593	7	Screened at WDL (1.63 V initial peaking)
12	620	8	Gaged engineering test cell
13	618	8	Gaged engineering test cell
14	706	8	Screened at WDL (failed charge retention)
15	694	8	Not screened at WDL
16	631	8	Screened at WDL (1.53 V peak at LT)
17	596	7	Screened at WDL (1.56 V peak at LT)
18	429	5	Screened at WDL (1.54 V peak at LT)
19	428	5	Screened at WDL (1.54 V peak at LT)
20	40	1	Screened at WDL (1.55 V peak at LT)
21	39	1	Screened at WDL (1.54 V peak at LT)
22	619	8	Gaged engineering test cell

*Special low temperature overcharge test at 0.15 A after screening tests.

Table 6-7. FACC Accelerated Life Test Cell Capacity Characteristics

Mfg Lot	Cell S/N	Post-Screening Burn-In Capacity	Season 2 Capacity	Season 3 Capacity	Season 9 Capacity	Percent Ratio of Season 9 to Post-Screening Capacity
1	11	–	–	–	1.26	–
1	12	–	–	3.15	0.74	–
1	20	–	–	4.00	3.54	–
5	403*	3.78	–	4.25	3.41	90.2
5	412	3.86	–	–	3.72	96.4
6	488	4.16	–	–	4.11	98.8
6	511*	4.04	–	4.25	3.62	89.6
7	540	3.60	–	4.10	3.65	101.4
7	545	3.66	–	–	2.96	80.9
7	547	3.50	–	–	2.96	84.6
7	593	3.50	–	3.30	1.83	52.3
8	620	–	–	–	1.26	–
8	618	3.77	3.15	–	1.13	30.0
8	706	4.08	–	–	1.70	41.7
8	694	–	–	–	1.84	–
8	631	4.31	–	–	0.78	18.1
7	596*	4.29	–	–	2.72	63.4
5	429	4.17	–	–	4.08	97.8
5	428	4.26	–	–	2.44	57.3
1	40	4.47	4.10	–	3.66	81.9
1	39	4.38	4.00	–	3.44	78.5
8	619	4.05	2.75	–	0.92	22.7

*Cells subsequently subjected to Load Sharing Test.

Cell capacity was then measured following the load sharing test at 10°C and the cells were discharged through 1-ohm resistors for six days. The cells were then stored in an open circuit discharged state for 34 days at room ambient conditions. A series of capacity tests were then performed at 20, 10, and 25°C, followed by a calculated 92 percent recharge efficiency test at 25°C for 91 hours. Square wave pulsing for this test consisted of a 120 mA charge for 500 ms and a 540 mA discharge for 102 ms.

Orbital Load Sharing Test

Twelve cells were chosen from the 20 cell group and tested for a calculated recharge efficiency of 86 percent at 25°C. One cell per week was removed from test for a capacity measurement to determine changes in state of charge with time. The capacities of all cells were determined after 3-1/2 months of load sharing. The cells were then recharged, calibra-

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Table 6-8. FACC Accelerated Life Test Minimum Cell Voltage at Equinox

Mfg Lot	Cell S/N	Seasons								
		1	2	3	4	5	6	7	8	9
1	11	1.170	1.139	1.094	1.042	1.038	1.008	0.932	0.722	*0.073
1	12	1.158	1.102	1.009	0.989	0.930	0.808	*0.185	*0.191	*0.219
1	20	1.207	1.200	1.182	1.190	1.192	1.188	1.183	1.177	1.166
5	403	1.201	1.193	1.172	1.183	1.184	1.177	1.168	1.159	1.150
5	412	1.197	1.190	1.172	1.168	1.181	1.180	1.173	1.166	1.158
6	488	1.217	1.218	1.204	1.201	1.207	1.211	1.209	1.205	1.198
6	511	1.204	1.202	1.183	1.190	1.190	1.187	1.179	1.172	1.158
7	540	1.214	1.203	1.186	1.186	1.195	1.190	1.186	1.180	1.175
7	545	1.198	1.155	1.110	1.189	1.130	1.105	1.107	0.996	0.799
7	547	1.199	1.165	1.132	1.123	1.154	1.110	1.056	1.035	1.022
7	593	1.194	1.141	1.048	1.002	1.066	0.998	0.957	0.943	0.705
8	620	1.140	0.764	0.748	0.735	0.787	0.690	0.439	*0.234	*0.248
8	618	—	1.178	1.084	0.912	0.968	0.959	0.936	0.811	0.480
8	706	—	1.183	1.123	1.087	1.108	1.021	0.997	0.968	0.927
8	694	—	1.216	1.195	1.186	1.192	1.186	1.183	1.174	1.166
8	631	—	1.186	1.116	1.055	1.071	0.989	0.947	0.706	*0.144
7	596	—	1.205	1.183	1.176	1.188	1.181	1.176	1.174	1.172
5	429	—	1.203	1.184	1.179	1.187	1.188	1.186	1.183	1.177
5	428	—	1.204	1.185	1.182	1.190	1.191	1.188	1.185	1.180
1	40	—	1.205	1.185	1.187	1.189	1.186	1.179	1.171	1.155
1	39	—	1.204	1.184	1.186	1.188	1.184	1.179	1.172	1.159
8	619	—	0.952	0.832	0.751	0.774	0.438	*0.169	*0.247	*0.256

*Cells reversed at end of discharge period causing no apparent cell deformation due to gas pressurization.

Table 6-9. Special Battery Cell Characterization Test Conditions

Cond. No.	Temp (°C)	Charge Rate	I_{chg} (mA)	(I_{disch}) (mA)				
				N_B = 98%	N_B = 90%	N_B = 85%	N_B = 80%	N_B = 60%
1	25	EOL Trickle Charge	71	–	320	–	–	–
2	25	EOL Intermediate Charge	121	–	545	–	484	–
3	25	BOL Intermediate Charge	140	–	630	–	560	–
4	25	BOL Full Charge	210	1029	945	–	840	–
5	20	BOL Full Charge	210	–	945	–	–	630
6	10	BOL Full Charge	210	–	945	–	840	630
7	25	EOL Intermediate (Life Test)	121	–	–	515	–	–

(1) $N_B = \dfrac{I_{disch} \cdot T_{dischg}}{I_{chg} \cdot T_{chg}}$

(2) $I_{disch} = \dfrac{V_B \cdot D}{pwr}$

where

I_{disch} = Pulsed battery discharge current in milliamps for a time period of T_{disch} in seconds (100 ms).

I_{chg} = Pulsed battery charge current in milliamps for a time period of T_{chg} in seconds (500 ms).

N_B = Forced battery recharge efficiency; equal to Q_{out}/Q_{in}.

V_B = Battery (20 cell) voltage; assumed equal to 27 V.

D = Discharge pulse duty cycle equal to 100 ms/ 600 ms = 1/6.

tion discharged, reconditioned, and subjected to a 20°C capacity measurement per Procedure SC-213728. Test data for this cell group are summarized on pages O-6 through O-8 (cell positions A1 through A12 of Appendix O.

Matrix Load Sharing Test

Eight cells remaining from the original 20 cell test group were subjected to matrix load sharing tests. Also included in these tests were three cells from Lots 5, 6, and 7 which had been cycled previously on the engineering life test. The matrix tests were performed for calculated recharge efficiencies ranging from 60 to 99 percent over a temperature range from 10 to 25°C. Data from these tests are summarized in Figures 6-11 through 6-16.

A trend of increased charge efficiency with reduced state of charge was observed for both Lots 5, 6 and 7 (SMS-TYPE) and Lots 10 and 12 (GOES-type) battery cells during the matrix load tests. Figure 6-11 through 6-16 illustrate this trend and also show an increase in cell state of charge for warmer temperatures (ranging from 10 to 27°C). Reduced capacity measurements for the SMS-type cells are the probable result of life cycling previously performed to simulate 5 years synchronous orbit equinox operation at 25°C without solstice simulation. Since the GOES type cells had no life cycle testing prior to the load sharing tests,

cell test data for these cells are representative of beginning of life performance. The SMS cell test data therefore would be more representative of end of life cell performance. The test results indicate that the charge rates evaluated had minimal effect on beginning and end of life cell capacity output for calculated recharge efficiencies ranging from 60 to 82 percent over a temperature range from 10 to 25°C. This trend continues for calculated efficiencies up to 93 percent at 25°C; however, cell capacity is reduced at 10°C for 90 percent efficiency.

Analysis of 3-1/2 month GOES cell load sharing test results shows no cell voltage or capacity degradation for a calculated recharge efficiency of 85 percent at 25°C. It is concluded that non-eclipse excess loads up to 515 mA per battery can be supported without capacity degradation, as illustrated in Figures 6-11 through 6-16. Although no predictions can be made relative to the long-term effects of load sharing, orbital battery load sharing on SMS-B has not produced any known adverse short-term effects on performance during summer solstice operations for 1976 and 1977.

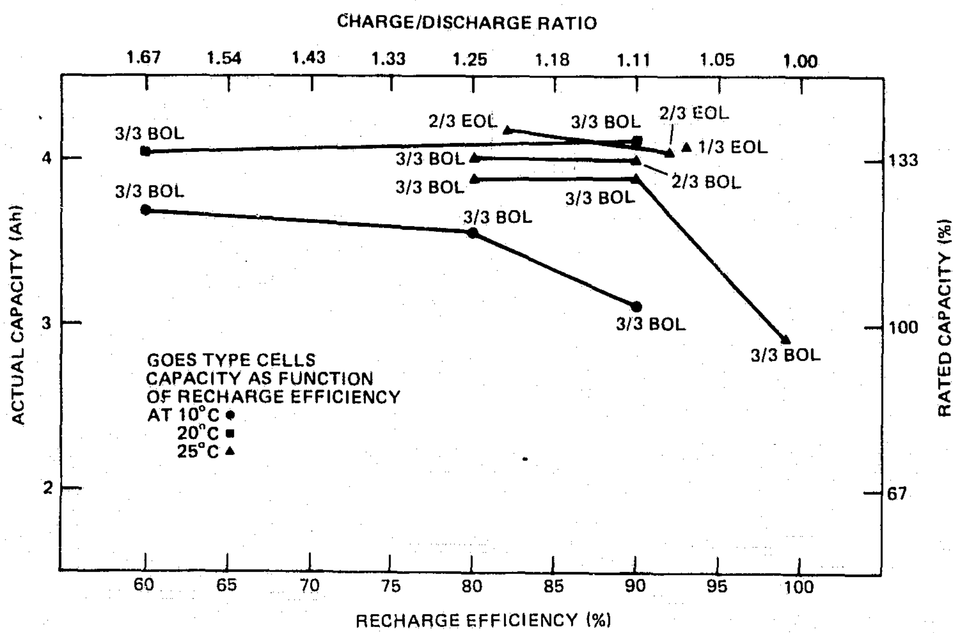

Figure 6-11. GOES Cell Load Sharing Capacity Characteristics at 10, 20, and 25°C

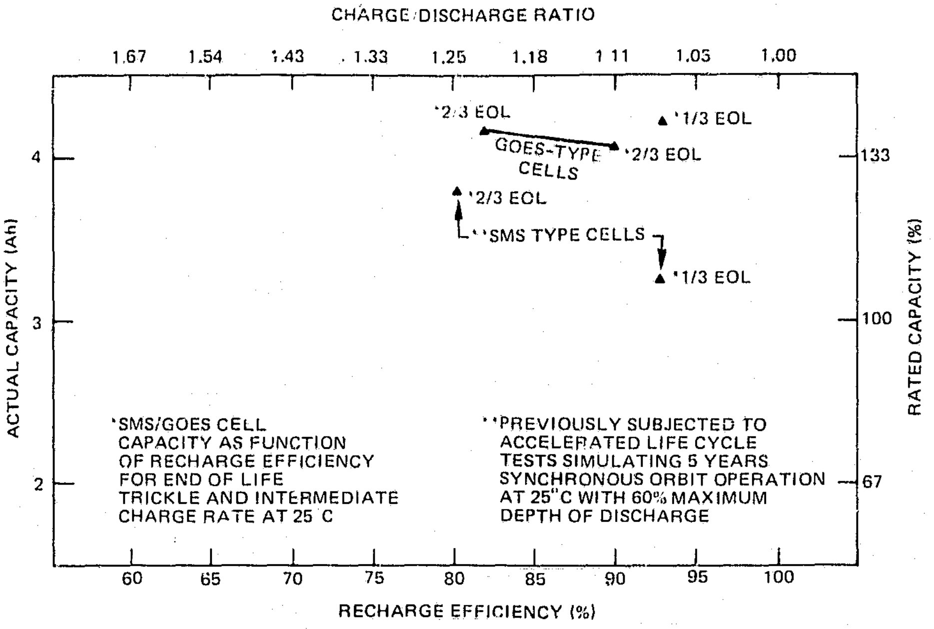

Figure 6-12. SMS/GOES Cell Load Sharing Capacity Characteristics at 25°C (Intermediate and Trickle Charge Rate)

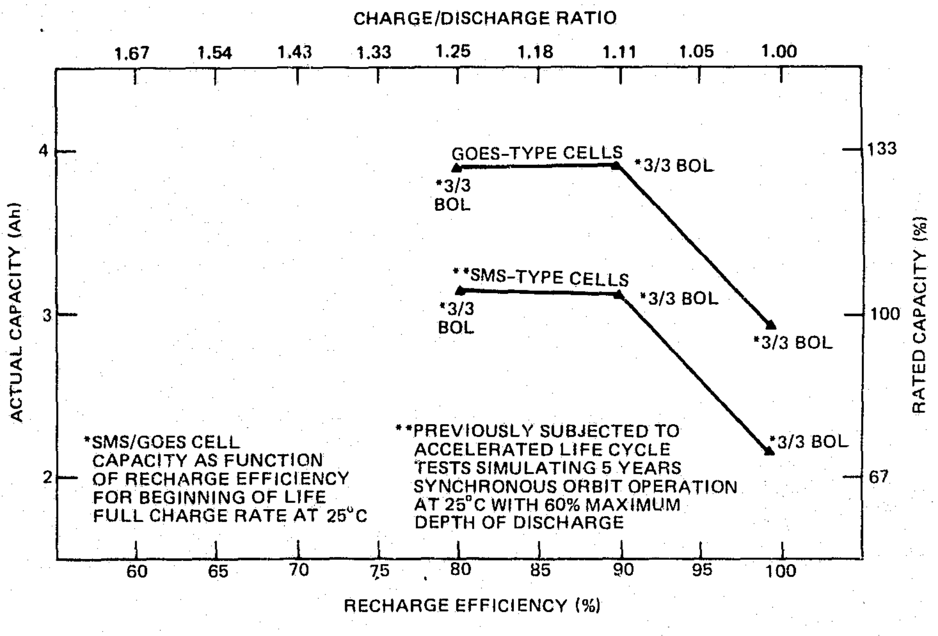

Figure 6-13. SMS/GOES Cell Load Sharing Capacity Characteristics at 25°C (Full Charge Rate)

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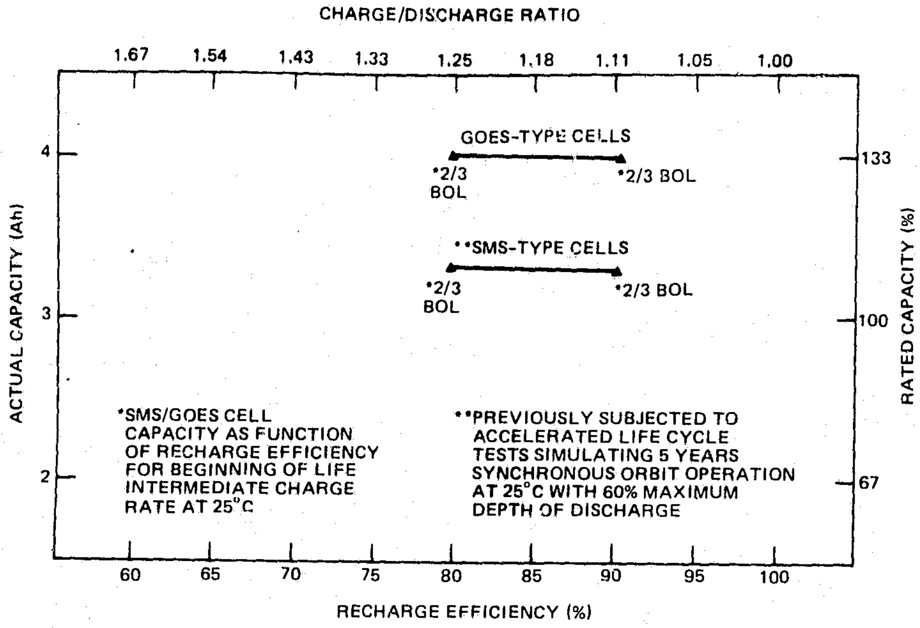

Figure 6-14. SMS/GOES Cell Load Sharing Capacity Characteristics at 25°C (Intermediate Charge Rate)

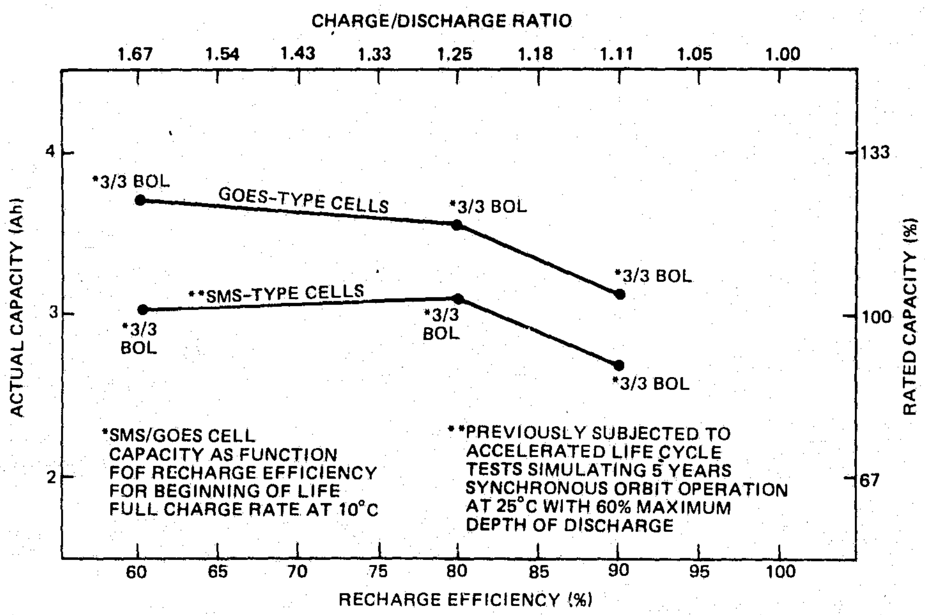

Figure 6-15. SMS/GOES Cell Load Sharing Capacity Characteristics at 10°C (Full Charge Rate)

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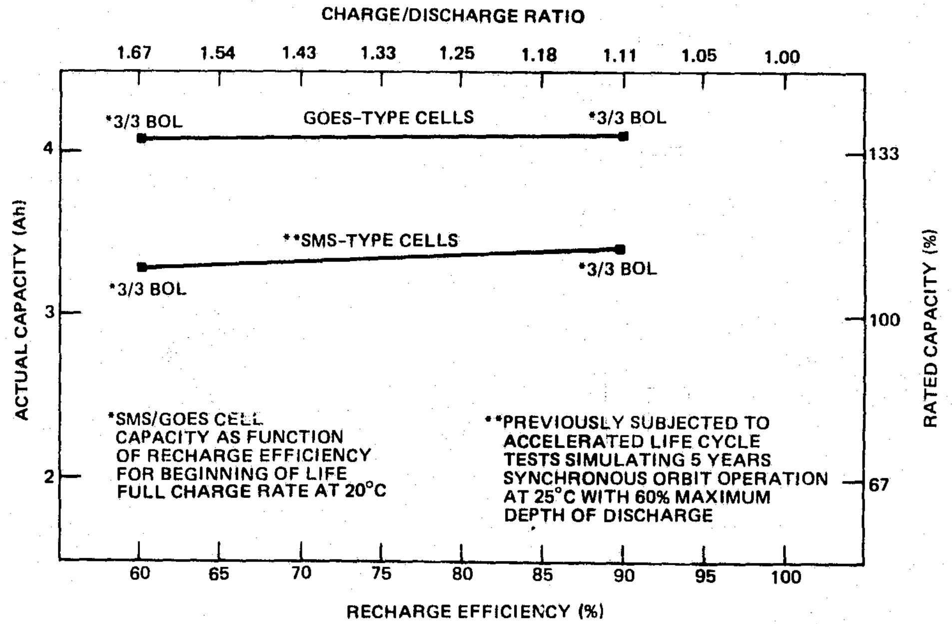

Figure 6-16. SMS/GOES Cell Load Sharing Capacity Characteristics at 20°C (Full Charge Rate)

SECTION 7

CONCLUSIONS

As a result of analysis of the SMS/GOES battery program cell development and flight hardware production at Eagle Picher Industries, the following observations and conclusions are set forth to highlight significant process and design parameter variables for the RSN-3 nickel-cadmium battery cell.

CELL DESIGN

- The selected cell design utilizes approximately 3.0 ml of 30 weight percent potassium hydroxide solution per ampere hour of measured positive capacity. This maximized value is equivalent to 17 to 18 percent of the total plate and separator weight (core weight) in added electrolyte.
- High rate charge/discharge (C/2 rate) formation cycling of plaques in the flooded electrolyte condition following active material impregnation appears to improve electrode efficiency, as observed for the Group II development cells. This may be a result of the plate surface and pores being cleared of loose material. Manufacturing control of variation in negative active material and electrochemical utilization is considered important in assuring adequate overcharge protection.
- Reduction of the cell container wall thickness from the standard 0.63 mm to 0.38 mm resulted in a 140 gram battery weight savings constituting 6.1 percent of the cell package weight.
- The positive plate active material loading range should be controlled to attain the desired positive plate capacity and required minimum negative-to-positive capacity ratio. Positive loading values in the range of 11.6 to 13.3 gm/dm^2 appear to be satisfactory based on production cell performance. Comparable negative plate active material loading values of 14.1 to 15.0 gm/dm^2 also provide adequate negative capacity. Deviation from either range can result in decreased cell performance, as demonstrated by cell manufacturing Lots 7 and 8.
- Since the amount of precharge measured following power discharge is usually greater than that calculated, this difference must be considered in determining the desired amount of electrochemically available discharged and charged excess negative capacity.
- Institution of plate tab-to-terminal weld process calibration measurements (including onsite pull tests, cross section examination, and other analytical tests) has been beneficial in controlling and monitoring critical weld joints.
- Separator physical properties and chemical analyses data compiled for this program, while appearing relatively divergent for specific measurements, are considered valuable information for future reference in the event of latent cell defects.
- Control of cell interelectrode spacing and/or plate thickness stability (with cycle life) appears important in avoiding separator dry out. This is evidenced by both initial high cell charging voltages for a fully discharged cell and a trend of degraded

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cell capacity for long life cycling. Cells from manufacturing Lots 7 and 8 were found to have reduced total interelectrode spacing of approximately 1.0 mm/cell compared with other flight cell production lots.

- Negative electrode state of charge adjustment appears to be satisactory for a discharged excess negative level of 60 percent or a measured precharge (electrochemical) value of approximately 40 percent. This is demonstrated by the acceptable maximum low temperature (2°C) overcharge voltages observed during cell screening and battery acceptance tests at FACC.
- Cells having reduced overcharge protection tend to have higher maximum charge voltages, particularly after extended short circuit storage for 24 months. An example of this is battery S/N 1005 (cell manufacturing Lot 6) where the calculated overcharge protection capacity was 1.07 Ah.
- FACC 5-year simulated synchronous orbit test results show that manufacturing Lots 7 and 8 cells have reduced end of discharge voltages (after 1.2 hours) and capacities at 25°C compared with Lot 5 and 6 cells which delivered approximately 90 to 100 percent of the original capacity after life test. As previously stated, cell separator dryout due to decreased interelectrode spacing is thought to be the principal degradation factor.

BATTERY DESIGN

Battery cell temperature gradients and variation were controlled to approximately 1.7°C during thermal vacuum testing by optimizing the T-rib (thermal) shunt material thermal conductivity and thickness.

- The SMS/GOES battery assembly mechanical package weight comprises approximately 10.1 percent of the total unit weight. The assembly design has demonstrated capability to withstand the Thor-Delta 2914 launch vehicle environment, including launch, ascent, and transfer orbit operation requirements.
- Weight savings realized through this battery design may be utilized to increase spacecraft payload capability or improve subsystem reliability by decreasing the battery depth of discharge for extended life. The SMS/GOES battery mechanical packaging design is independent of battery cell manufacturing processes and designs and can be readily applied to existing or new battery cell designs.

MISSION PERFORMANCE

The SMS/GOES battery configuration meets all anticipated operational requirements while performing the required energy storage function. There is high probability that the satellite batteries will attain the expected orbital life based on accelerated life test results and orbital battery performance to date.

- GOES-B and -C battery cell Lots 10 and 12 appear to have enhanced peak overcharge voltage capability due to reduced positive loadings and a higher measured negative-to-positive electrochemical capacity ratio. The GOES-Band-C cells had a negative to positive ratio in excess of 1.60, compared with a 1.40 to 1.54 ratio for the SMS and GOES-A battery cells (except for the Lot 8 cells which had a measured ratio of 1.83, accomplished by high negative plate loadings).

- Although no prediction can be made for the long-term effect of pulse loading the SMS/GOES batteries during solstice season operation, experimental results indicate that full capacity can be maintained over the short term for a 110 percent capacity return at 25°C. However, the battery state of charge is decreased to approximately 75 percent for a 110 percent capacity return at 10°C.

APPENDIX A

SMS BATTERY ASSEMBLY DESIGN SPECIFICATION SD-212066

PHILCO

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303

SPECIFICATION NO. SD-212066

TITLE

SMS

BATTERY ASSEMBLY

DESIGN SPECIFICATION

Date Verified
12-6-74
Verified
D. Costa

PROGRAM/SITE SMS			PRIME CONTRACT NUMBER NAS5-21575		
Spec. Engr.	J. Kramer	Date 7-15-71	SRB Chairman	L. Nelson	Date 8-2-71
Resp. Engr.	R. J. Haas / R. Haas	Date 7-16-71	Program Office	John Savides / J. Savides	Date 8/5/71
Quality Assurance	C. Barron for T. Whittemore	Date 7-23-71			Date
			Outside WDL		
Subsystem Manager	L. C. Faber, Jr. 7-16-71 / L. Faber				
System Manager	R. Robinson 7/23/71 / R. Robinson				
			Release Date	ENGR DATA AUG 5 1971	Page 1 of 15

WDL-572A (9-69)

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1. SCOPE

This specification establishes the requirements for performance and design of the nickel-cadmium battery assembly, for use on the Synchronous Meterological Satellite (SMS). The battery is to provide electrical energy during pre-launch and eclipses and supplementary energy during peak load periods.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of issue noted, constitute a part of this specification to the extent specified herein. Should a conflict exist, this specification shall govern.

PUBLICATIONS

NASA

SP-5002 (Fourth Edition)	Soldering, Electrical Connections
NHB-5300.4 (1B)	Quality Program Provisions for Aeronautical and Space System Contractors
NHB-5300.4 (3A)	Requirements for Soldered Electrical Connections
PPL-11	GSFC Preferred Parts List

STANDARDS

Military

MIL-STD-130C	Identification Marking of U.S. Military Property
MIL-STD-143B	Standards and Specifications, Order of Procedence for the Selection of
MIL-STD-454B	Standard General Requirements for Electronic Equipment

2.2 The following documents, of issue noted, constitute a part of this specification to the extent specified herein.

SPECIFICATIONS

Philco-Ford

SH-212002	SMS Environmental Requirements Specification
ST-A20403	SMS General Quantitative Reliability Assessment Specification
SD-212061	SMS Power Control Unit Design Specification
SP-212064A	SMS nickel-cadmium battery cell (3.0 ampere hour) Procurement Specification

PLANS

Philco-Ford

TR-4487	SMS quality Assurance Program Plan
SA-212067	SMS Power Subsystem Test Plan
TR-4492	SMS Reliability Program Plan
SA-212037	Electromagnetic Compatability Control Plan
TR-4546	Magnetic Field Control Plan

DRAWINGS

Philco-Ford

HZ-211103	SMS Battery Assembly Interface Control Drawing
99-213827	SMS Battery Assembly Drawing

3. REQUIREMENTS

3.1 General.- The battery assembly for the SMS power subsystem shall consist of one battery of series-connected battery cells. The battery shall contain twenty hermetically sealed nickel-cadmium cells of three ampere-hour capacity and two thermal sensors. The battery shall supply energy for pre-launch, hold, abort, launch/ascent, solar eclipse and peak non-eclipse operations. The role of the battery in the electrical power subsystem is defined in the SMS Power Control Unit Design Specification, SD-212061.

3.2 Electrical.

3.2.1 Battery Assembly Electrical Requirements.- Battery assembly performance and electrical requirements are specified in Tables I and II. The maximum eclipse period is 1.2 hours and the charge time during eclipse seasons ranges from 22.8 to 24.0 hours. The battery shall incorporate 20 battery cells with electrical characteristics as delineated in Procurement Specification SP-212064.

3.2.2 Battery Assembly Thermal Sensors.- The battery assembly shall be equipped with two thermistors, located to measure the maximum cell case temperature. The temperature/resistance characteristics of the thermistors over a temperature range of -10°C to +50°C shall be as shown in Figure 1. Thermistor accuracy in the temperature range indicated shall be within 1 percent of the resistance values shown.

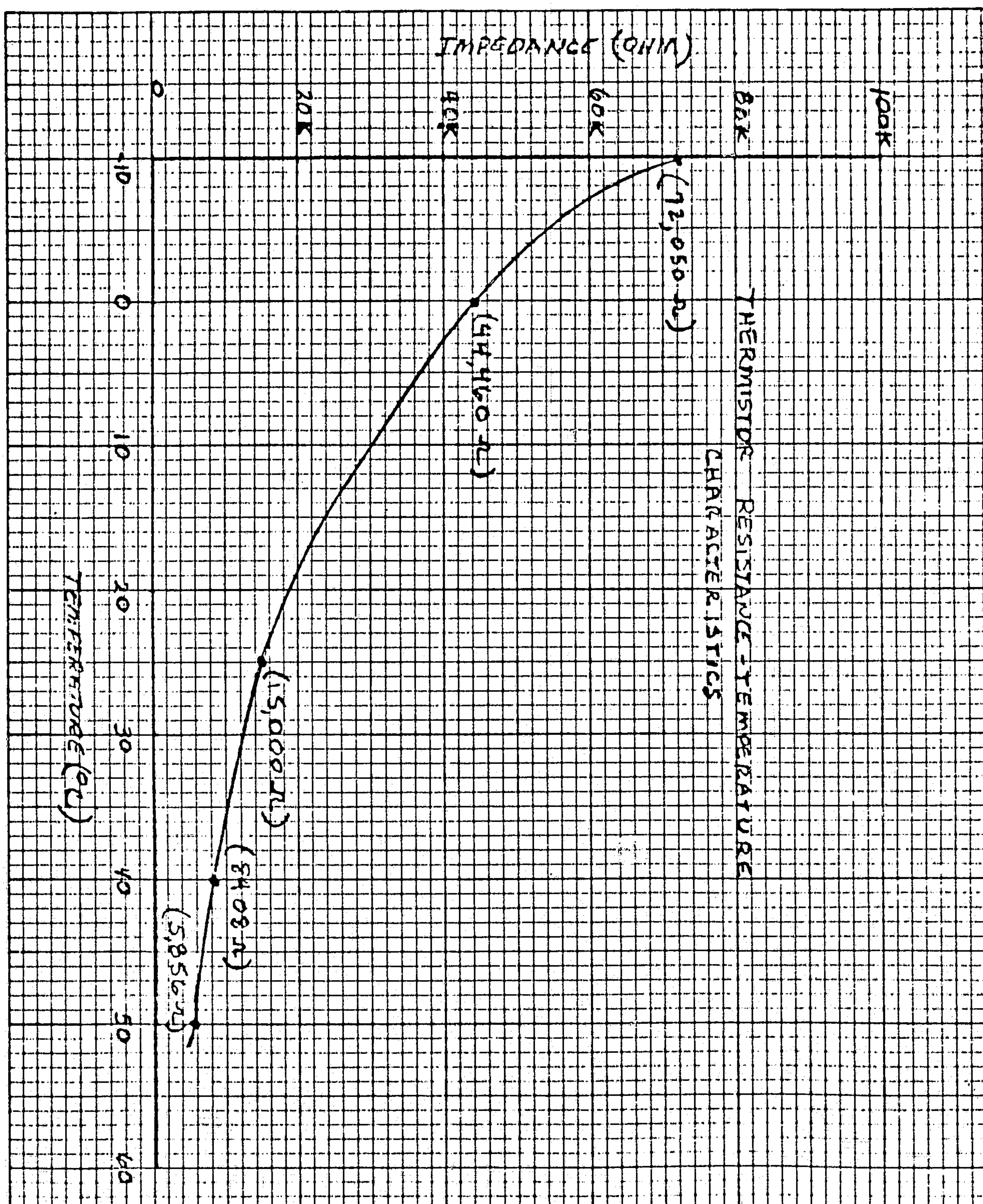

IMPEDANCE (OHM)
0
20K
40K
60K
80K
100K
THERMISTOR RESISTANCE-TEMPERATURE
CHARACTERISTICS
TEMPERATURE (°C)
-10
0
10
20
30
40
50
60
(72,050 Ω)
(44,460 Ω)
(15,000 Ω)
(8408 Ω)
(5,856 Ω)

FIGURE 1

3.2.3 Insulation Resistance. - The electrical resistance between the battery case and battery connector leads, between battery case and battery cell case and between battery connector leads and thermistor leads shall be 10 megohms minimum at a potential of 100 (+10,-0) volts.

3.2.4 Internal Impedance. - The battery internal impedance measured at the battery terminals shall be in accordance with Paragraph 3.2.16.2, Battery Interface, of SD-212061 when exposed to any combination of storage and operating conditions specified herein.

3.2.5 Charge Retention. - To demonstrate the absence of a soft short, Battery cells shall be capable of recovery to an open circuit voltage of at least 1.16 volts after experiencing the following load conditions in the sequence shown.

a. Discharge down to a level of 1.0 volts.

b. A one ohm load for a period of 16 hours followed by a direct short for a period of one hour.

c. 24 hours in an open circuit condition.

3.3 Design and Construction.

3.3.1 Interface Definition.

3.3.1.1 Interface Requirements. -The battery assembly shall interface with the Power Control Unit through the electrical distribution subsystem as per HZ-211103.

3.3.1.2 Mechanical Interface. - The battery assembly shall be mounted on the support structural subsystem in accordance with provisions of HZ-211103.

3.3.1.3 Functional Interfaces. - The battery assembly shall supply power and signals to the Electrical Power Subsystem, as specified in Power Control Unit Design Specification SD-212061. The electrical interfaces with the power control unit shall be in accordance with HZ-211103.

TABLE I
SMS Battery Assembly, Performance Requirements

CHARACTERISTIC	VALUE
Nominal Battery Load (to 60% of discharge)	36.5 watts
Maximum Depth of Discharge, % of Nominal Capacity	60, during orbital operation
Rated Battery Capacity (Nominal)	3.0 Ampere Hours
Peak Discharge Current	27.0 Amperes, 100 milliseconds
Nominal Discharge Current	1.5 Amperes
Maximum Discharge Time	1.2 Hours
Maximum Steady State Discharge Current	8.0 Amperes
Allowable Charging Current Range	0.2 to 0.3 Amperes
Trickle Charge Current Range	0.07 to 0.10 Amperes
Maximum Allowable Charge Time	22.8 Hours
Total Cycles and Eclipse (5 years)	440 cycles
Cycle Repetition Rate (charge/discharge)	24 hours
Maximum Trickle Charge Period	≈ 138 days between cycle periods
Orbital Life	5. years
Battery Cell Configuration	1-twenty cell Assembly (2 x 10 cells)
Maximum Battery Heat Output During Overcharge	9. Watts (equivalent)
Maximum Allowable Battery Cell Temperature Gradient	5°C
Allowable Battery Temperature Range during orbital operation (thermistor measurement)	5°C - 30°C
Qualification Temperature Range (thermistor measurement)	0°C to 40°C
Maximum Battery Charge Voltage	30.0 Volts
Minimum Battery Discharge Voltage	20.0 Volts
Minimum Discharge Voltage For 5 Cell groups in the Battery	5.0 Volts

TABLE II

SMS Battery Assembly Capacity Performance Requirements

Temp. (°C)	Discharge Current (Amps)	Discharge Time (Hrs)	Min. Voltage (Volts)	Min.Req'd.% Rated Cap. 100%=3.(Amp Hrs)	Max Allowable Cell Capacity Difference (Amp Hrs)
24 ±2	1.5	2.0	20.00	100%	0.15
0 ±2	1.5	1.5	20.00	75%	0.30
40 ±2	1.5	1.0	20.00	50%	0.40
5°C to 30°C	1.5	1.7	20.00	85%	0.25

3.3.2 General Design Features.- The battery assembly design shall conform to the requirements of drawing HZ-211103 and is described in greater detail in drawing 99-213827. The battery assembly shall consist of twenty 3.0 ampere hour battery cells connected in series and restrained in position by the battery structural subassembly.

3.3.2.1 Weight.- The weight of the battery assembly shall be as specified in drawing HZ-211103.

3.3.2.2 Corrosion Resistance.- All external surfaces of the battery assembly shall show no evidence of corrosion when exposed to the environment conditions specified herein.

3.3.2.3 Leakage.- The battery assembly shall show no evidence of electrolyte leakage when subjected to the specified storage and operating conditions.

3.3.2.4 Thermal Properties.- The battery assembly shall have thermal properties as specified on drawing HZ-211103. The battery structural assembly shall be designed to maintain the battery temperature within the specified temperature range of 5°C to 30°C for the heat output profile delineated in HZ-211103. The maximum allowable mean temperature difference from cell to cell in the battery assembly shall be 5°C.

3.3.2.5 Connector. - The connector used on the battery assembly shall conform to the requirements of drawing HZ-211103.

3.4 Performance. (Refer to 3.2.)

3.5 Parts, Materials and Processes. - Parts, materials and process selection, evaluation, qualification, testing and screening shall be conducted and documented in accordance with the SMS Reliability and Quality Assurance Program Plans and as specified herein.

3.5.1 Parts, Materials and Process Specifications and Standards. - All parts, materials and processes used shall be described in specifications and/or standards covering their procurement, inspection, testing/screening, handling and/or utilization.

3.5.2 Parts.

3.5.2.1 Electrical/Electronic Part Selection. - To the maximum extent feasible, electrical/electronics parts shall be selected from NASA/GSFC PPL-11; all other parts shall be designated non-standard. Selection of non-standard parts shall be on the basis of demonstrated, or potential for demonstration of, suitability for the SMS mission.

3.5.2.2 Electrical/Electronic Part Qualification. - Each non-standard part shall have a non-standard part approval request form prepared and submitted to NASA/GSFC for review and approval prior to use, together with such documentation as may be required to support the request. In the event part qualification status has not been established, qualification testing may be required.

3.5.2.3 Electrical/Electronic Part Screening. - All Electrical/electronic parts shall be subject to 100 percent screening as indicated in the applicable portions of the screening matrix contained in the SMS Reliability Program Plan and the Parts Specification.

3.5.2.4 Part Traceability. - All parts shall be traceable to manufacturer lot.

6-2

3.5.3 Materials.

3.5.3.1 Outgassing. - Because this equipment will be located in close proximity to satellite optical devices, materials used shall be selected for minimum outgassing and release of volatile contaminants in the ascent and orbital environments.

3.5.3.2 Protective Treatment. - Where materials used in the construction of the unit are subject to deterioration when exposed to climatic, handling, and environmental conditions likely to occur during service usage, they shall be protected against such deterioration in a manner that will in no way prevent compliance with the requirements of this specification. The use of any protective coating that will crack, chip, or scale with age or extremes of climatic and environmental conditions shall be avoided.

3.5.3.3 Dissimilar Metals. - Dissimilar metals, as defined in MIL-STD-454, Requirement 16, shall not be used in immediate contact with each other. Adjacent surfaces shall be suitably coated or otherwise protected against electrolytic corrosion.

3.5.3.4 Moisture and Fungus Resistance. - Materials which are adversely affected by moisture or which are nutrient to fungi shall not be used unless effective protective treatment is provided. Requirement 4 of MIL-STD-454 shall apply.

3.5.3.5 Toxic Materials. - Materials which will produce harmful or toxic effects during handling, operation or storage shall not be used.

3.5.3.6 Materials Traceability. - All materials shall be traceable to manufacturer's lot.

3.5.4 Processes.

3.5.4.1 Fabrication Techniques. - The processes used in fabrication of equipment defined by this specification shall follow written procedures selected from NASA/GSFC approved process control procedures, Government, or Industry Standards.

3.5.4.2 Soldering. - Soldering shall conform to the requirements of NHB 5300.4 (3A). SP-5002 shall be used as a guide.

3.5.5 Interchangeability and Replacement. - All parts having the same manufacturer's part number shall functionally and dimensionally interchangeable. The provisions of MIL-STD-454, Requirement 7, shall apply.

3.5.5.1 Identification and Marking. - Each piece of equipment furnished under this specification shall have a nameplate for identification. Identification, marking and serialization shall be in accordance with Standard MIL-STD-130, except the nameplate shall be placed directly upon the exterior surface by stenciling, silk screening or an equivalent process. The following data shall be included on each equipment nameplate:

a. Item designation:

b. Manufacturer's part number:

c. Manufacturer's serial number:

d. Prime Contract Number: NAS5-21575.

3.5.5.2 Serialization. - All assemblies and subassemblies thereof shall be serialized for ease of identification.

3.6 Specifications and Standards. - The selection of specifications and standards for commodities and services not otherwise specified herein shall be in accordance with MIL-STD-143.

3.7 Workmanship. -Standards of workmanship shall meet or exceed requirement 9 of MIL-STD-454.

3.8 Environmental Requirements. - The equipment shall meet the design and performance requirements specified herein during and after any probable combination of operation environments and/or subsequent exposure to non-operational environments as specified in SR-212002.

3.9 Electromagnetic Interference. - The requirements of SA-212037 shall apply.

3.9.1 Magnetic Field Control.- The provisions of Magnetic Field Control Plan TR-4546, apply to the design and performance of the equipment.

3.10 Reliability.- Reliability requirements are as specified in TR-4492 the SMS Reliability Program Plan, and as defined in 3.10.1 through 3.10.3.

3.10.1 Shelf Life Requirement.- The equipment shall have the capability of meeting all requirements specified herein after a shelf life of at least two (2) years when suitably packaged and protected against detrimental factors such as corrosive atmospheres and dust.

3.10.2 Life Requirements.- The battery assembly shall have an operating life (in synchronous orbit) of not less than five (5) years. This life shall include all of the environmental excitations and exposures of the SMS mission profile including prelaunch operations, launch/boost and transfer orbit phases.

3.10.3 Success Probability Requirement.- The reliability shall be assessed according to the methods of ST-A20403, SMS Quantitative Reliability Assessment Specification.

3.10.3.1 Pre-Launch and Launch Survival.- The equipment shall survive the specified pre-launch and launch environments and placement into orbit in readiness for operation (P_L) with a probability of not less than 0.9999.

3.10.3.2 Orbit Survival.- The equipment shall successfully perform its designated and specified function in the specified orbited environment for a period of five years with a probability of success (P_S) of not less than 0.9538, assessed over the mission as described in ST-A20403 and including the cycles of discharge associated with eclipse periods and charge maintenance in the balance of the mission.

4. QUALITY ASSURANCE PROVISIONS

4.1 General.- Quality Assurance shall be implemented in accordance with the requirements of the SMS Quality Assurance Program Plan, TR-4487, and NBH 5300.4 (1B).

4.2 Tests.- Tests shall be conducted in accordance with the requirements of the SMS Power Subsystem Test Plan, SA-212067. Battery cell source test procedures shall be in accordance with Procurement Specification SP-212064.

4.3 Rejection Criteria.- Permanent rejection is required if any of the following has occurred to an individual cell:

a. Unit was exposed to temperatures outside the -40°C to +50°C range regardless of time duration of over-temperature exposure.

b. Unit had received currents in excess of 30 amperes (10 C rate).

c. Unit was over discharged below 0.0 volts after activation.

d. Unit was physically damaged in any manner, such as from being dropped from a height greater than 1.0 inch.

e. Unit failure to pass any electrical test.

5. PREPARATION FOR DELIVERY

5.1 Preservation, Packaging and Packing. - After completion of tests, each battery shall be preserved within one week by performing the following:

a. Discharge each cell below 0.1 volt by clipping a one ohm resistor across the cell terminals.

b. Remove the one ohm resistor and short the cell terminals by wrapping a copper wire around cell terminals.

c. Place each battery in a polyethylene bag and add an inert drying agent to exclude moisture. Heat seal each bag.

NOTE: Battery Assembly serial number shall be clearly visible from the outside of the bag.

d. Package each unit in a manner to avoid damage during shipment.

NOTE: For long term storage (periods in excess of one week) batteries shall be stored in a clean dry area at a temperature between 10 to 28°C.

5.2 Marking for Shipment and Storage. - All marking on shipping containers shall be clearly legible from a distance of 36 inches and may be applied by stencil, number stamp or lacquer over coated gummed labels.

The equipment furnished hereunder is for space flight use. All marking shall be blue in color and in addition, all shipping containers and shipping documents shall be marked as follows:

"ITEMS FOR SPACE FLIGHT USE"

5.3 Electrical Cycling Instructions.- Each Battery Assembly shall be provided with one copy of the essential cycling instructions which shall be consistent with the reconditioning requirements of paragraph 6.3.

6. NOTES

6.1 Intended Use. - The Batteries covered by this specification are intended for continuous duty in electrical systems of the SMS satellite. They will be used in combination with a solar cell array to provide energy storage and furnish peak power demands.

6.2 Definitions. -

6.2.1 Battery Capacity. - Battery capacity is the discharge measured quantitatively in ampere hours at the specified discharge rate to the specified cell cutoff voltage.

6.2.2 Cutoff Voltage. - The cutoff voltage of a cell is defined as that discharge voltage which represents the complete discharge condition of the cell for a particular rate. Discharge beyond this voltage would yield an insignificant amount of useful energy.

6.2.3 Constant Current Discharge. - The discharge made at the rate specified until the final voltage reaches the specified cutoff value.

6.3 Reconditioning. - Depending on the use history of a Battery, the responsible Engineer may utilize the following reconditioning procedure prior to any test.

6.3.1 Reconditioning Procedure.-

a. Discharge the battery to 20 volts at the c/2 rate (1.5 amps)

b. Recharge the battery for 40 hours at the c/20 rate (0.15 amps)

c. After discharge of the battery to 20.0 volts at the c/2 rate, place one ohm resistors across each cell terminals for 24 hours.

d. Charge the battery at 0.3 amperes for 16.0 hours.

e. Discharge the battery to 23.0 volts at the c/2 rate (1.5 amps).

f. Continue discharge to 20.0 volts at the c/2 rate.

g. Repeat step c. then short each cell for a 1.0 hour period minimum.

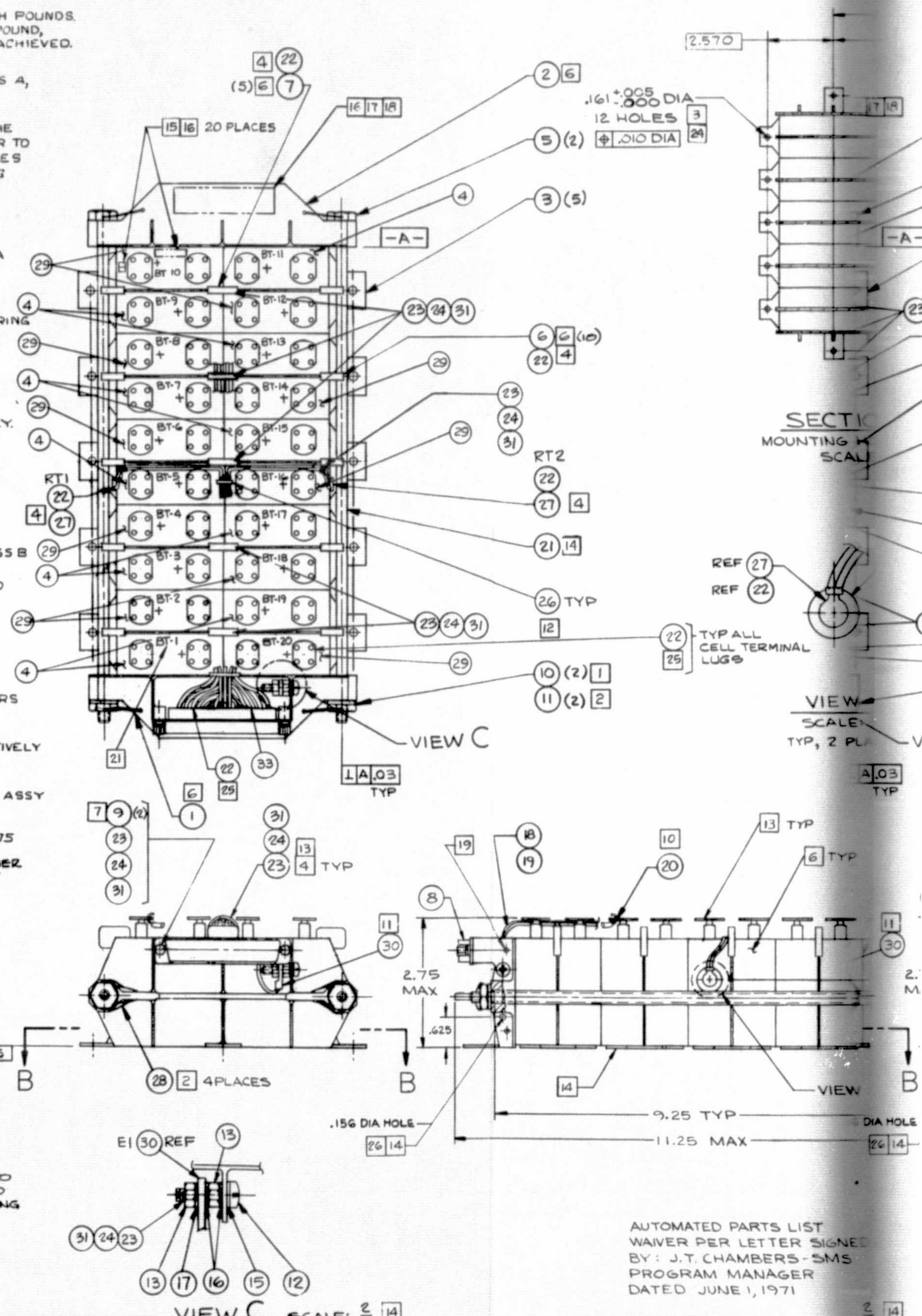
APPENDIX B

SMS BATTERY DESIGN 213827
AND
WIRING DIAGRAM DRAWING 213828

FOLDOUT FRAME

NOTES (UNLESS OTHERWISE SPECIFIED)

1. TORQUE PER WDL STD 88-5111, 12 TO 15 INCH POUNDS. TORQUE EACH OF THE (2) FIND NO. 10 INCH POUND, ALTERNATELY, UNTIL REQUIRED TORQUE IS ACHIEVED.
2. SAFETY WIRE PER WDL STD 88-7011, CLASS A, TYPE III.
3. BOLT HOLES SHALL BE DRILLED AFTER THE BATTERY ASSEMBLY IS COMPLETE AND PRIOR TO APPLICATION OF FINISH. THE MOUNTING FLANGES SHALL BE SUPPORTED DURING THE DRILLING OPERATION.
4. BOND PER WDL STD 88-4032 TYPE II
5. FINISH PER WDL STD 88-3016 TYPE II GRADE A WITH FIND NO. 25 AND 32 REFER TO NOTES 6 AND 13
6. APPLY FINISH TO THIS AREA PRIOR TO WIRING
7. TORQUE PER WDL STD 88-6111 REV 2 TABLE 1.
8. WIRE PER DW-213828
9. REF DESIGNATIONS ARE SHOWN FOR REF ONLY. FOR COMPLETE DESIGNATION, PREFIX WITH UNIT NO. OR SUB-ASSY DESIGNATION.
10. SOLDER PER NHB 5300.4(3A)
11. CRIMP PER WDL STD 88-5011
12. LACE PER WDL STD 88-5519, TYPE II, CLASS B
13. APPLY FINISH AFTER SOLDERING LACING AND BONDING
14. OMIT FINISH THIS AREA
15. MARK CELL SERIAL NO. AND + POLARITY MARK AFTER APPLICATION OF FINISH.
16. STENCIL PER MIL-STD-130 .12 HIGH CHARACTERS LOCATE APPROX. AS SHOWN.
17. BATTERIES SHALL BE NUMBERED CONSECUTIVELY STARTING WITH THE NUMBER 1001
18. MARKING INFORMATION: 11530-SMS BATTERY ASSY
    213827-01
    SERIAL NO. XXXX
    CONTR NO. NAS5-21575
19. HOLES ARE FOR SUPPORT OF WEIGHTS. NUMBER AND SIZE OF WEIGHTS TO BE DETERMINED AT TIME OF BALANCING.
20. TEST PER SB213716.
21. REFERENCE DESIGNATIONS BT-1 THRU BT-20 ARE SHOWN FOR BATTERY WIRING SCHEMATIC ONLY.
22. FOR ASSEMBLY PROCEDURES SEE SC-213772.
23. BATTERY WEIGHT SHALL BE 7.9 LBS. MAX.
24. REWORKED BATTERY MOUNTING HOLE PATTERN SHALL BE MAINTAINED, BUT HOLES MAY BE ELONGATED UP TO .050 INCHES IN ANY DIRECTION.
25. APPLY SEALANT TO THIS AREA AFTER FINISHING. SEALANT MAY BE THINNED WITH TOLUENE UP TO TWO PARTS BY VOLUME.
26. REMOVE ANODIZE SURFACE COATING TO RADIUS OF 0.160 AFTER FINISHING AND COAT PER 88-9008 PARA 6.2 COATING OPTION B, DOW 19.



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AUTOMATED PARTS LIST WAIVER PER LETTER SIGNED BY: J.T. CHAMBERS-SMS PROGRAM MANAGER DATED JUNE 1, 1971

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NOTES (UNLESS OTHERWISE SPECIFIED)

1. TORQUE PER WDL STD 88-5111, 12 TO 15 INCH POUNDS. TORQUE EACH OF THE (2) FIND NO. 10 INCH POUND, ALTERNATELY, UNTIL REQUIRED TORQUE IS ACHIEVED.
2. SAFETY WIRE PER WDL STD 88-7011, CLASS A, TYPE III.
3. BOLT HOLES SHALL BE DRILLED AFTER THE BATTERY ASSEMBLY IS COMPLETE AND PRIOR TO APPLICATION OF FINISH. THE MOUNTING FLANGES SHALL BE SUPPORTED DURING THE DRILLING OPERATION.
4. BOND PER WDL STD 88-4012 TYPE II
5. FINISH PER WDL STD 88-3016 TYPE II GRADE A WITH FIND NO. 25 AND 32 REFER TO NOTES 6 AND 13
6. APPLY FINISH TO THIS AREA PRIOR TO WIRING
7. TORQUE PER WDL STD 88-6111 REV 2 TABLE 1.
8. WIRE PER DW-213828
9. REF DESIGNATIONS ARE SHOWN FOR REF ONLY. FOR COMPLETE DESIGNATION, PREFIX WITH UNIT NO. OR SUB-ASSY DESIGNATION.
10. SOLDER PER NHB 5300.4(3A)
11. CRIMP PER WDL STD 88-5011
12. LACE PER WDL STD 88-5519, TYPE II, CLASS B
13. APPLY FINISH AFTER SOLDERING LACING AND BONDING
14. OMIT FINISH THIS AREA
15. MARK CELL SERIAL NO. AND + POLARITY MARK AFTER APPLICATION OF FINISH.
16. STENCIL PER MIL-STD-130 .12 HIGH CHARACTERS LOCATE APPROX. AS SHOWN.
17. BATTERIES SHALL BE NUMBERED CONSECUTIVELY STARTING WITH THE NUMBER 1001
18. MARKING INFORMATION: 11530-SMS BATTERY ASSY
    213827-01
    SERIAL NO. XXXX
    CONTR NO. NAS5-21575
19. HOLES ARE FOR SUPPORT OF WEIGHTS. NUMBER AND SIZE OF WEIGHTS TO BE DETERMINED AT TIME OF BALANCING.
20. TEST PER SB213716.
21. REFERENCE DESIGNATIONS BT-1 THRU BT-20 ARE SHOWN FOR BATTERY WIRING SCHEMATIC ONLY.
22. FOR ASSEMBLY PROCEDURES SEE SC-213772.
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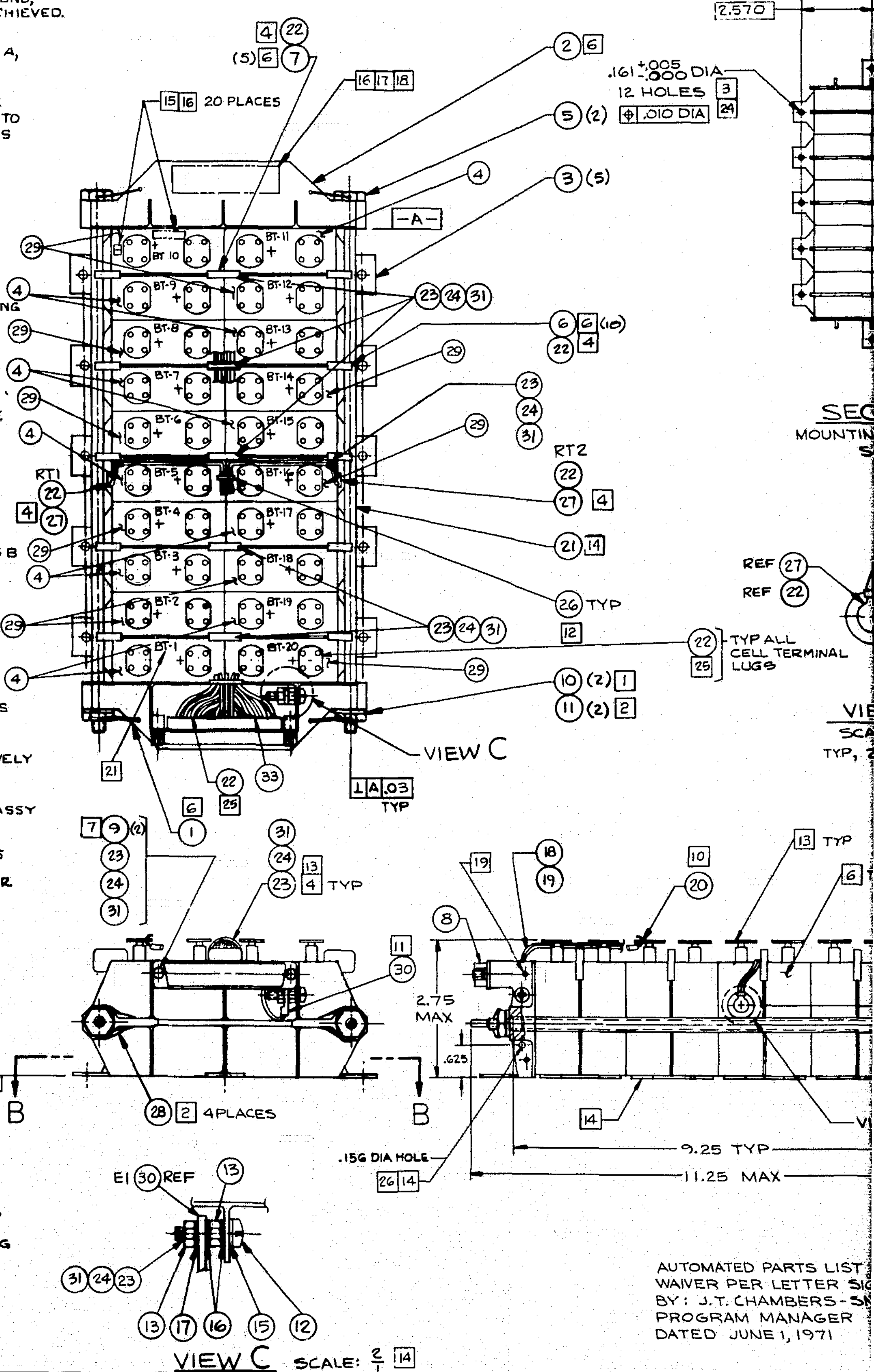
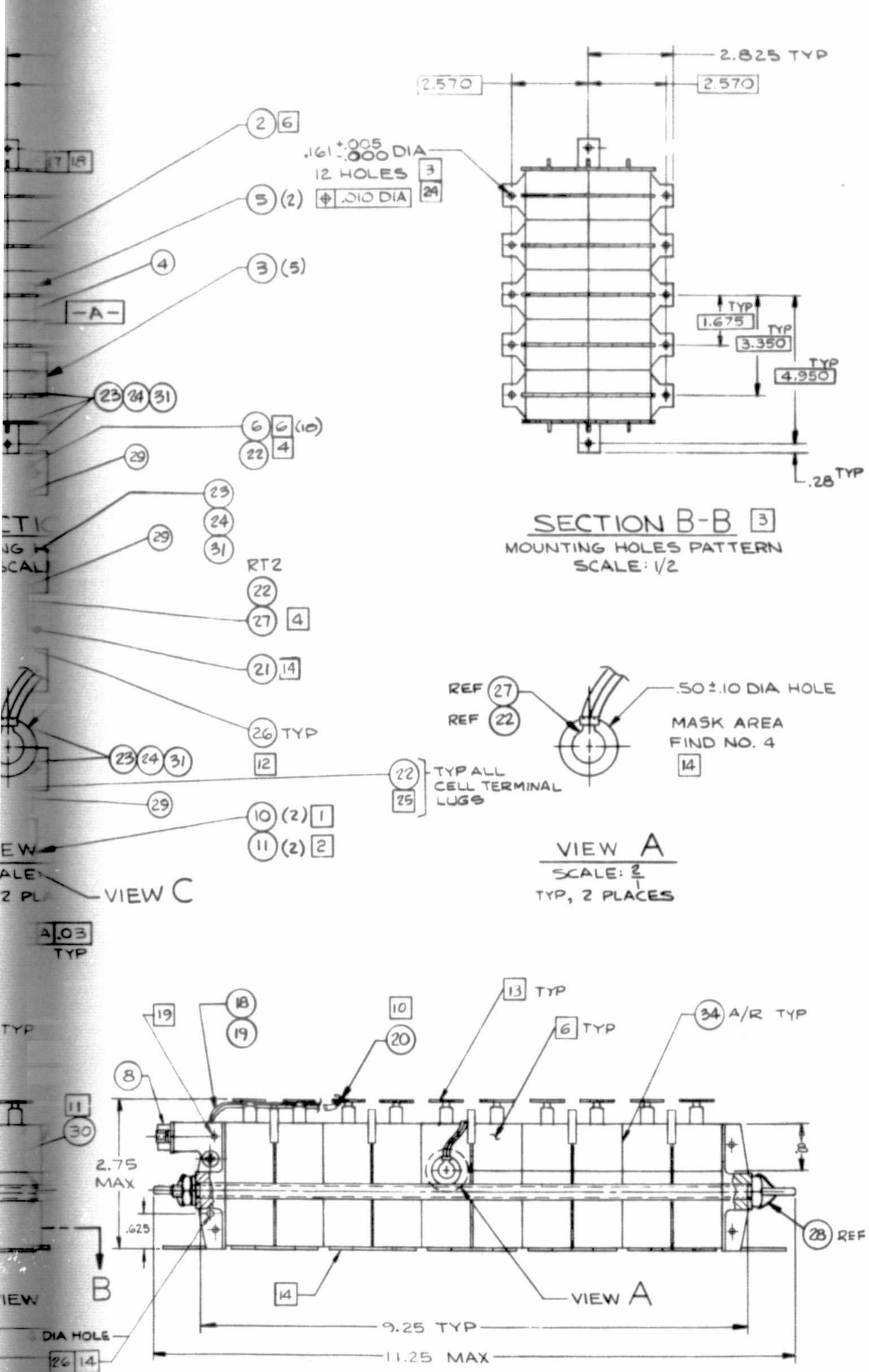
25. APPLY SEALANT TO THIS AREA AFTER FINISHING. SEALANT MAY BE THINNED WITH TOLUENE UP TO TWO PARTS BY VOLUME.
26. REMOVE ANODIZE SURFACE COATING TO RADIUS OF 0.160 AFTER FINISHING AND COAT PER 88-9008 PARA 6.2 COATING OPTION B, DOW 19.





REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	(A1) INC PER ECO B03977 (A2) INC PER ECO B03981		
	B	(B1) INC ECO C7965 (B2) INC ECO C8239 (B3) INC ECO D4785 (B4) INC ECO C4793 (B5) INC ECO B02642 (B6) INC ECO B02643 (B7) INC ECO B02644 (B8) INC ECO B02647 (B9) INC ECO D4968		

FIND NO.	QTY	CODE IDENT	PART NO.	NOMENCLATURE/DESCRIPTION	SPEC	NOTE
34	A/R		05-P12097-XXXX	MYLAR, SHEET, SHIMS		
33	A/R		08-P12107-0002	SLEEVING, SHRINK		
32			11-020077-0001 A&B	PRIMER WASH		5
31			11-P12013-0001	SILICA, PYROGENIC		4
	REF	11530	88-5011	CRIMPED SOLDERLESS CONN.		
	REF	96906	MIL-STD-130	IDENTIFICATION, MARKING		6
	REF	11530	88-3016	FINISHES, PAINT		5
	REF		88-5519	LACING		12
	REF		88-7011	WIRING, SAFETY		2
	REF		88-4002	BONDING, ADHESIVE		4
	REF		88-6111	TORQUEING		7
	REF		88-6003	SOLDERING		10
30	1	11530	23-P10070-0003	LUG, WIRE, 24 AWG		11
29	10	11530	40-213831-02	CELL, BATTERY		
	REF	11530	DW-213828	WIRING DIAGRAM		
28	A/R	96906	MS20995-AA47	WIRE, SAFETY		2
27	2	11530	52-P11050-0001	THERMISTOR		4
26	A/R	82110	12-020056-0001	LACING		12
25	A/R	30676	11-020054-0001	PAINT, FLAT BLACK		5
24	A/R	11530	23-P12137-0001	CATALYST, EPOXY		4
23	A/R		23-P12146-0001	ADHESIVE, BONDING, EPOXY		4
22	A/R		23-P12351-0003	SEALANT, DC6-1104		4 25
21	A/R		08-P12117-0023	TUBING, TEFLON		
20	A/R		09-P12024-0003	SOLDER, SN60		10
19	A/R		03-P12104-0040	WIRE, AWG, 24 GA, WHT		
18	A/R		03-P12104-0020	WIRE, AWG, 20 GA, WHT		
17	1		25-P10044-0011	WASHER, FLAT, NO. 6		
16	2		MS35335-58	WASHER, LOCK, EXT-TOOTH, NO. 6		
15	1		25-P10063-0003	WASHER, LOCK, SPLIT, NO. 6		
14						
13	2		25-P10067-0003	NUT, HEX, 6-32		
12	1		25-P10074-0031	SCR, MACH, PAN HD, 6-32 x [illegible]		
11	2		25-P10044-0021	WASHER, FLAT, NO. 1/4		
10	2		25-213835-01	NUT, HEX		1 2
9	2		25-P10013-0001	SCREW ASSEMBLY		7
8	1		41-P10052-0008	CONNECTOR		
7	5		21-213834-01	BLOCK, SUPPORT, CENTER		
6	10		21-213833-01	BLOCK, SUPPORT, CORNER		
5	2		25-213832-01	BOLT		
4	10		40-213831-01	CELL, BATTERY		
3	5		20-213830-01	RIB, CELL SUPPORT		
2	1		20-213829-12	PLATE, END		
1	1	11530	20-213829-01	PLATE, END		

PARTS LIST

213827 B

AUTOMATED PARTS LIST
WAIVER PER LETTER SIGNED
BY: J.T. CHAMBERS - SMS
PROGRAM MANAGER
DATED JUNE 1, 1971

01	99-211000
DASH	NEXT ASSY

APPLICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. TOLERANCES: DEC .X ± .1, DEC .XX ± .01, DEC .XXX ± .005, FRACTIONS ± —, ANGLES ± —

STD DRILL TOLERANCES PER AND 10387

~~MARK PER 88-7001 TYPE~~

MATL
SPEC
FIN. 5

DR 19 JUN 71
CHK 19 JUN 71
DESIGNER
DSGN ENGR
RELEASE 8-4-71

CONTRACT NO. NAS 5-21575

PHILCO — PHILCO-FORD CORPORATION, WDL Division, Palo Alto, California

POWER SUPPLY, BATTERY

SIZE	CODE IDENT	
F	NO. 11530	213827

SCALE 1/1 — SHEET 1 OF 1

CM-75

B-1/B-2

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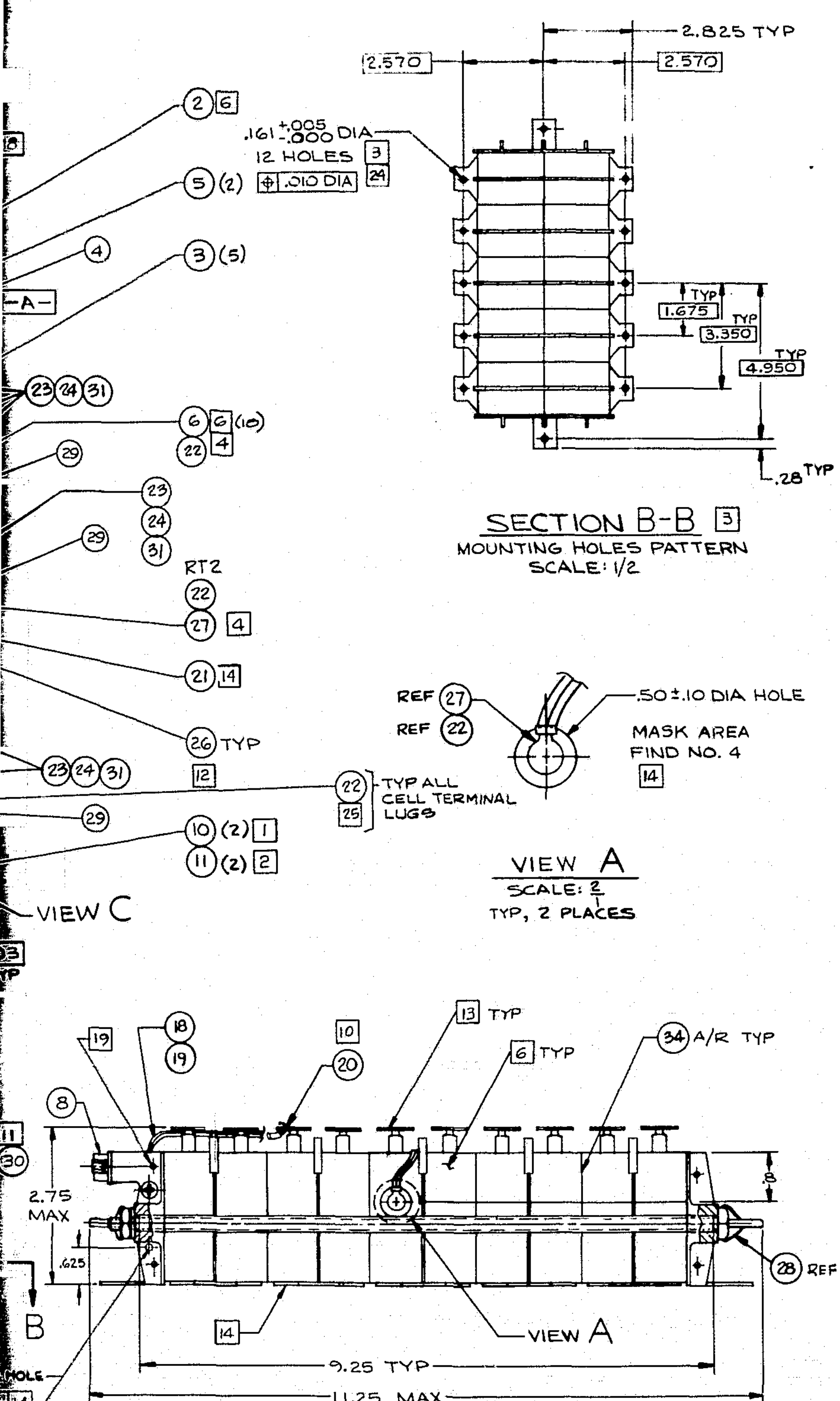

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	(A1) INC PER ECO B03977 (A2) INC PER ECO B03981		
	B	(B1) INC ECO C7965 (B2) INC ECO C8239 (B3) INC ECO D47__ (B4) INC ECO _4783 (B5) INC ECO B02642 (B6) INC ECO B02643 (B7) INC ECO B02644 (B8) INC ECO B02647 (B9) INC ECO D4968	10-10-73	

FIND NO.	QTY	CODE IDENT	PART NO.	NOMENCLATURE/DESCRIPTION	SPEC	NOTE
34	A/R		05-P12097-XXXX	MYLAR, SHEET, SHIMS		
33	A/R		08-P12107-0002	SLEEVING, SHRINK		
32			11-020077-0001 A&B	PRIMER WASH		5
31			11-P12013-0001	SILICA, PYROGENIC		4
	REF	11530	88-5011	CRIMPED SOLDERLESS CONN.		
	REF	96906	MIL-STD-130	IDENTIFICATION, MARKING		16
	REF	11530	88-3016	FINISHES, PAINT		5
	REF		88-5519	LACING		12
	REF		88-7011	WIRING, SAFETY		2
	REF		88-4002	BONDING, ADHESIVE		4
	REF		88-6111	TORQUEING		7
	REF		88-6003	SOLDERING		10
30	1	11530	23-P10070-0003	LUG, WIRE, 24 AWG		11
29	10	11530	40-213831-02	CELL, BATTERY		
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28	A/R	96906	MS20995-AA47	WIRE, SAFETY		2
27	2	11530	52-P11050-0001	THERMISTOR		4
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25	A/R	30676	11-020054-0001	PAINT, FLAT BLACK		5
24	A/R	11530	23-P12137-0001	CATALYST, EPOXY		4
23	A/R		23-P12146-0001	ADHESIVE, BONDING, EPOXY		4
22	A/R		23-P12351-0003	SEALANT, DCG-1104		4 25
21	A/R		08-P12117-0023	TUBING, TEFLON		
20	A/R		09-P12024-0003	SOLDER, SN60		10
19	A/R		03-P12104-0040	WIRE, AWG, 24 GA, WHT		
18	A/R		03-P12104-0020	WIRE, AWG, 20 GA, WHT		
17	1		25-P10044-0011	WASHER, FLAT, NO. 6		
16	2		MS35335-58	WASHER, LOCK, EXT-TOOTH, NO.6		
15	1		25-P10063-0003	WASHER, LOCK, SPLIT, NO.6		
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12	1		25-P10074-0031	SCR, MACH, PAN HD, 6-32 x [illegible]		
11	2		25-P10044-0021	WASHER, FLAT, NO. 1/4		
10	2		25-213835-01	NUT, HEX		1 2
9	2		25-P10013-0001	SCREW ASSEMBLY		7
8	1		41-P10052-0008	CONNECTOR		
7	5		21-213834-01	BLOCK, SUPPORT, CENTER		
6	10		21-213833-01	BLOCK, SUPPORT, CORNER		
5	2		25-213832-01	BOLT		
4	10		40-213831-01	CELL, BATTERY		
3	5		20-213830-01	RIB, CELL SUPPORT		
2	1		20-213829-12	PLATE, END		
1	1	11530	20-213829-01	PLATE, END		

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CONTRACT NO. NAS 5-21575

PHILCO — PHILCO-FORD CORPORATION, WDL Division, Palo Alto, California

POWER SUPPLY, BATTERY

SIZE F | CODE IDENT NO. 11530 | 213827

SCALE 1/1 | SHEET 1 OF 1

40

CM-75

B-1/B-2

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APPENDIX C

STRUCTURAL ANALYSIS OF SMS BATTERY ASSEMBLY

EMR-71-101
MAY 1971

STRUCTURAL ANALYSIS
OF
SMS BATTERY ASSEMBLY

D.M. KELLEY

PREPARED BY: David M Kelley
CHECKED BY: ______
APPROVED BY: JWG, DES

CONTENTS

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◦ INTRODUCTION AND SUMMARY.

THIS REPORT PRESENTS AN ANALYSIS EVALUATING THE STRUCTURAL CHARACTERISTICS OF THE SMS BATTERY ASSEMBLY FOR COMPLIANCE WITH CURRENT SMS ENVIRONMENTAL REQUIREMENTS AS DOCUMENTED IN REFERENCE 1. IN ADDITION TO SURVIVING THE ENVIRONMENTAL LOADINGS, THE ASSEMBLY MUST ALSO SURVIVE A CELL FAILURE WHICH PRODUCES AN ADDITIONAL 250 psi PRESSURE LOAD.

THE BATTERY ASSEMBLY CONFIGURATION TO BE ANALYZED WAS SPECIFIED BY THE POWER SUBSYSTEM DESIGN AND INTEGRATION SECTION. SCHEMATICS OF THE CONFIGURATION (SUPPLIED BY RON HAAS) ARE SHOWN ON THE FOLLOWING PAGES. THE BATTERY ASSEMBLY IS TO BE FABRICATED OF A MAGNESIUM ALLOY. DESIREABLE RANGES OF SIZES FOR EACH COMPONENT OF THE ASSEMBLY WERE ALSO SUPPLIED.

IN ORDER TO FACILITATE A SIMPLIFIED ANALYSIS, CERTAIN BASIC ASSUMPTIONS WERE MADE. AMONG THESE ARE:

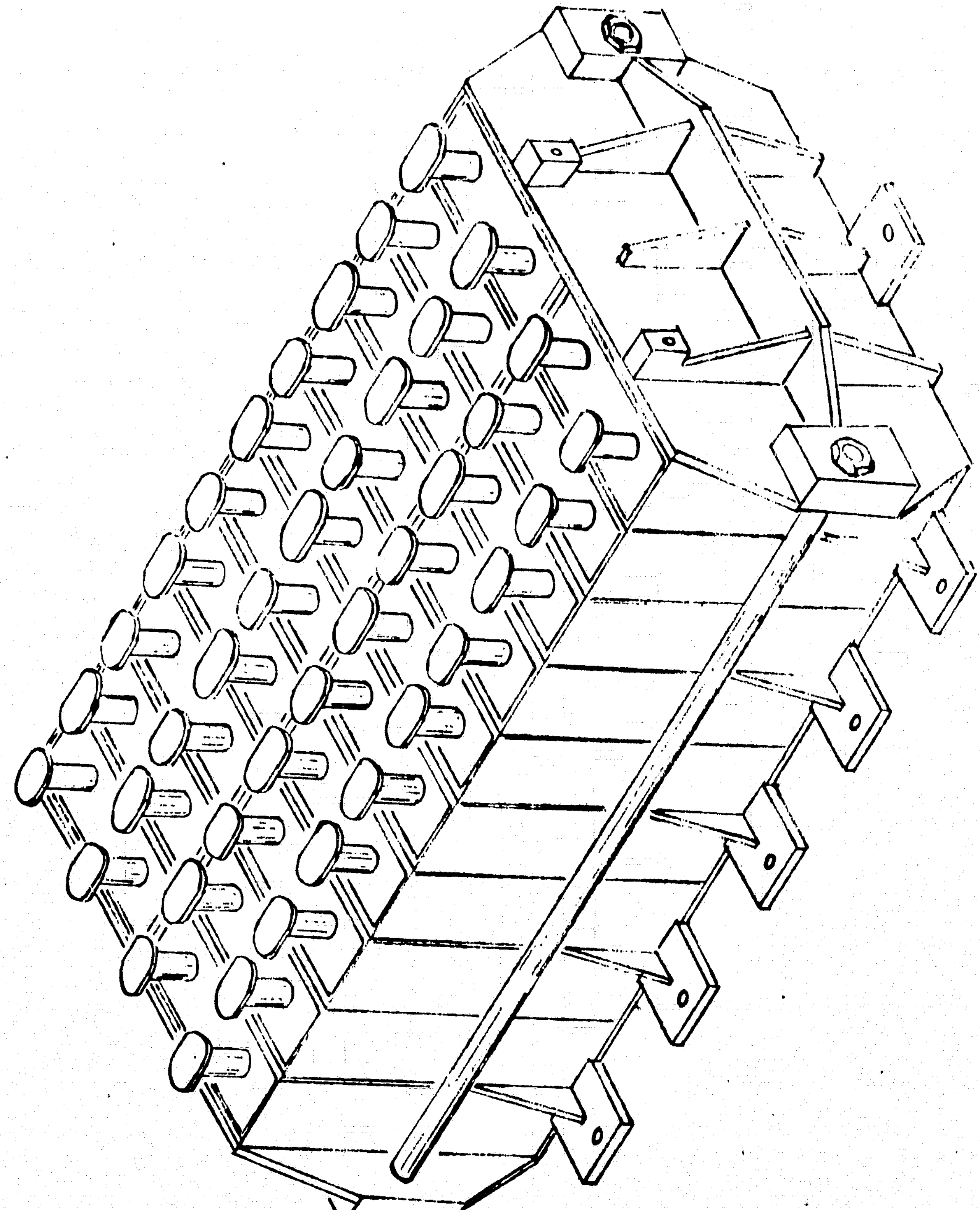
1. THE BATTERY ASSEMBLY BEING SMALL AND COMPACT HAS A HIGH NATURAL FREQUENCY OF VIBRATION - IN THE RANGE OF 100-300 Hz.

2. SINCE THE ASSEMBLY IS COMPOSED OF FIVE CELL UNITS CLAMPED TOGETHER, INTERNAL FRICTION IS HIGH AND THE SYSTEM EXHIBITS MODERATE STRUCTURAL DAMPING - OF THE ORDER OF 15%.

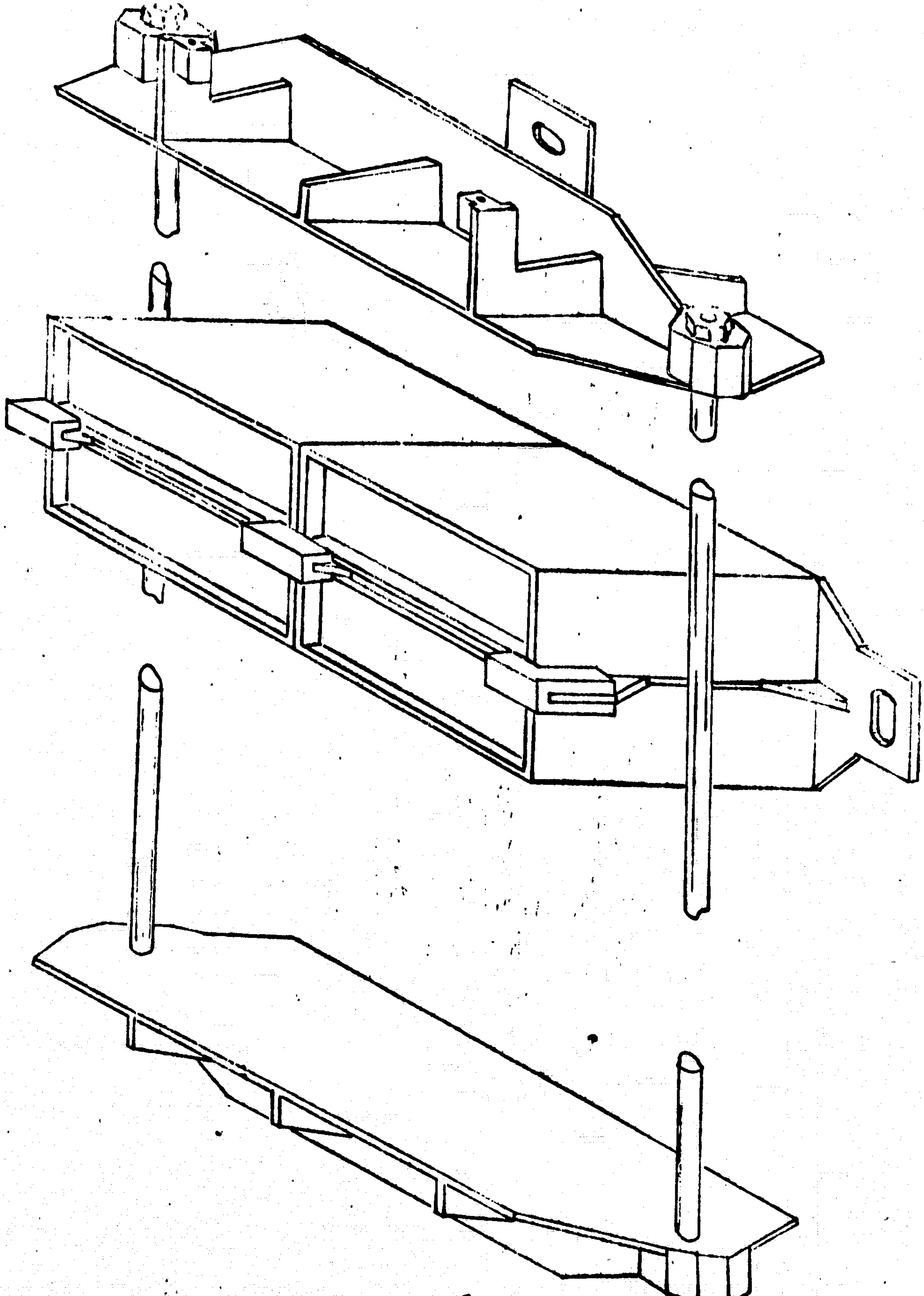
3. IN SIZING THE VARIOUS COMPONENTS OF THE ASSEMBLY, EACH CELL UNIT OF FOUR CELLS IS ASSUMED TO ACT INDEPENDENTLY AND THE BATTERY END PLATES ARE ASSUMED TO RESIST ONLY THE LOAD REQUIRED TO CLAMP THE ASSEMBLY TOGETHER AND THE CELL FAILURE LOAD OF 250 psi.

ANY OTHER ASSUMPTIONS WHICH ARE MADE ARE SPECIFIED WITHIN THE REPORT PROPER.

THE ASSEMBLY DESIGNED SUMMARIZED IN TABLE 1 WILL SURVIVE AN ULTIMATE LOADING OF 48 g AND A LIMIT LOADING OF 32 g IN ALL DIRECTIONS AS WELL AS A CLAMPING TORQUE ON EACH THROUGH BOLT OF 15 in-lb AND A CELL FAILURE LOAD OF 250 psi. THE FINAL DESIGN WEIGHT IS 7.678 lbs. TABLE 2 SUMMARIZES THE DESIGN STRESSES AND FACTORS OF SAFETY (F.S.). THE MINIMUM FACTOR OF SAFETY IS 1.12 AGAINST FAILURE OF THE END PLATE MAIN SUPPORT WEB IN SHEAR DUE TO THE CLAMPING AND CELL FAILURE LOADS ON THE THROUGH BOLTS.



SMS BATTERY SCHEMATIC



SMS BATTERY CELL SCHEMATIC

TABLE 1. SUMMARY OF FINAL DESIGN		
COMPONENT	DIMENSION	MATERIAL
CELL SUPPORT RIBS		
WEB	t = .030 in	Mg HM21A-T8
FLANGE	t = .055 in	Mg HM21A-T8
END PLATES		
FACE FLANGE	t = .025 in	Mg HM21A-T8
MAIN SUPPORT WEB		
ADJACENT TO BOLT SEATS	t = .225 in	Mg HM21A-T8
BETWEEN SIDE WEBS	t = .100 in	Mg HM21A-T8
SIDE WEBS	t = .025 in	Mg HM21A-T8
THROUGH BOLT SEATS	ℓ = .500 in	Mg HM21A-T8
CONNECTOR SEATS	ℓ = .250 in	Mg HM21A-T8
THROUGH BOLTS	12-28	Al 2024-T4
TIE-DOWN BOLTS	10-32	Al 2024-T4

TABLE 2. SUMMARY OF DESIGN STRESSES AND FACTORS OF SAFETY				
LOCATION	ULTIMATE		YIELD	
	σ_{cr} (ksi)	F.S.	σ_{cr} (ksi)	F.S.
CELL SUPPORT RIB				
WEB SHEAR	0.9	23.35	0.6	20.00
WEB TENSION	3.9	8.46	2.6	6.92
FLANGE SHEAR	1.3	16.15	0.9	13.35
FLANGE BENDING	23.6	1.40	15.8	1.14
FLANGE BEARING	3.6	13.05	2.4	12.10
END PLATE				
MAIN SUPPORT WEB SHEAR	18.8	1.12	5.4	2.22
MAIN SUPPORT WEB BENDING	26.6	1.24	11.9	1.51
SIDE WEB SHEAR	—	—	10.1	1.19
THROUGH BOLT TENSION	54.3	1.14	15.5	2.58
TIE-DOWN BOLT TENSION	1.9	17.45	1.3	13.85
TIE-DOWN BOLT SHEAR	2.1	10.00	1.4	8.58

• LOADS. COMPONENTS OF THE SMS SATELLITE MUST BE DESIGNED TO SURVIVE SPECIFIC SINUSOIDAL AND RANDOM VIBRATION LOADINGS AS WELL THE SUSTAINED ACCELERATION LOADINGS OF THE LAUNCH. THIS SECTION DEFINES THESE LOADINGS BOTH AS ULTIMATE AND LIMIT LOADS. SURVIVAL OF ULTIMATE LOADS IS DEFINED AS NOT EXCEEDING ULTIMATE STRESS LEVELS. SURVIVAL OF LIMIT LOADS IS DEFINED AS NOT EXCEEDING YIELD STRESS LEVELS. THE FOLLOWING LOADINGS WERE OBTAINED FROM REFERENCE 1.

• SUSTAINED ACCELERATION LOADS. SUSTAINED ACCELERATION LOADS ON EACH COMPONENT ARE THE VECTOR SUMS OF THE MAXIMUM LONGITUDINAL ACCELERATION RESULTING FROM THE LAUNCH THRUST AND THE MAXIMUM RADIAL ACCELERATION DUE TO THE SATELLITE SPIN. THE MAXIMUM LONGITUDINAL ACCELERATION IS 16.8 g's FOR ULTIMATE LOADING AND 11.2 g's FOR LIMIT LOADING. THE MAXIMUM RADIAL ACCELERATION IS 0.516 r g's FOR ULTIMATE LOADING AND 0.344 r g's FOR LIMIT LOADING, WHERE r IS THE DISTANCE OF THE COMPONENT FROM THE SPIN AXIS MEASURED IN INCHES. FOR STANDARDIZATION OF SUSTAINED ACCELERATION LOADINGS ON ALL COMPONENTS, r HAS BEEN CHOSEN AS THE MAXIMUM DISTANCE TO ANY COMPONENT, i.e. 38 in. (IF THE RESULTING LOADING IS TO SEVERE AND THE POSITION OF THE COMPONENT IN THE SATELLITE HAS BEEN FIXED, THE ACTUAL DISTANCE MAY BE USED IN COMPUTING THE MAXIMUM RADIAL ACCELERATION.) THUS THE MAXIMUM RADIAL ACCELERATION IS 19.6 g's FOR ULTIMATE LOADING AND 13.1 g's FOR LIMIT LOADINGS. THE RESULTING SUSTAINED ACCELERATION LOADS ARE 25.8 g's FOR ULTIMATE LOADING AND 17.2 g's FOR LIMIT LOADING. THESE LOADS MUST BE APPLIED IN EACH OF THREE ORTHOGONAL DIRECTIONS WITH A DURATION OF ONE MINUTE IN EACH DIRECTION.

• SINUSOIDAL VIBRATION LOADS. SINUSOIDAL VIBRATION LOADS ON EACH COMPONENT FOR ULTIMATE AND LIMIT LOADINGS ARE TABULATED ON THE FOLLOWING PAGE FOR VARIOUS RANGES OF THE EXCITING FREQUENCY.

TABLE 3. SINUSOIDAL VIBRATION LOADS			
DIRECTION OF EXCITATION	FREQUENCY RANGE (Hz)	g LEVEL	
		ULTIMATE	YIELD
XX, YY	5 - 10	.5" d.a.	.3" d.a.
	10 - 20	14.0	9.3
	20 - 100	4.0	2.7
	100 - 200	2.0	.7
	200 - 2000	5.0	3.3
ZZ	5 - 11	.5' d.a.	.3" d.a.
	11 - 17	3.0	2.0
	17 - 23	7.0	4.7
	23 - 30	12.5	8.3
	30 - 60	25.0	16.7
	60 - 80	8.0	5.3
	80 - 200	3.0	2.0
	200 - 2000	5.0	3.3

• RANDOM VIBRATION LOADS. RANDOM VIBRATION LOADS ON EACH COMPONENT FOR ULTIMATE LOADINGS ARE TABULATED BELOW FOR VARIOUS RANGES OF FREQUENCY.

TABLE 4. RANDOM VIBRATION LOADS			
FREQUENCY RANGE (Hz)	PSD (g^2/Hz)	ACC. (g - rms)	DURATION
20 - 40	ROLL-OFF BELOW 40 Hz AT RATE OF 6dB/OCTAVE	10.9	4 MINUTES EACH AXIS
40 - 300	.18		
300 - 600	ROLL-OFF AT RATE OF 6dB PER OCTAVE		
600 - 2000	.045		

• GOVERNING LOADS. THE LOADING WHICH GOVERNS THE DESIGN OF THE SMS BATTERY ASSEMBLY STRUCTURE DEPENDS UPON THE RESPONSE OF THE STRUCTURE TO BOTH SINUSOIDAL AND RANDOM EXCITATIONS. THAT IS, THE ACCELERATION LOADING RESULTING FROM THESE EXCITATIONS MAY BE CONSIDERABLY HIGHER THAN THE SUSTAINED ACCELERATION LOADING.

FROM HURTY AND RUBINSTEIN (REF. 2) THE RESPONSE OF A STRUCTURE MODELED AS A SINGLE DEGREE-OF-FREEDOM SYSTEM SUBJECTED TO A SINUSOIDAL EXCITATION, $\ddot{f}(t) = \ddot{F} \sin \Omega t$, IS GIVEN BY THE FOLLOWING FORMULA:

$$\ddot{y}(t) = |H(\Omega)|^2 \ddot{F} \sin \Omega t,$$

WHERE $H(\Omega)$ IS THE SYSTEM MAGNIFICATION FACTOR. THIS FACTOR IS GIVEN BY:

$$H(\Omega) = \frac{1}{1-(\Omega/\omega)^2 + ig},$$

WHERE ω IS THE NATURAL FREQUENCY OF THE SYSTEM AND g IS THE AMOUNT OF STRUCTURAL DAMPING IN THE SYSTEM. THE MAXIMUM VALUE OF THE MAGNIFICATION FACTOR OCCURS AT $\Omega = \omega$ AND IS:

$$H(\omega) = \frac{1}{ig}.$$

THE NATURAL FREQUENCY OF THE BATTERY ASSEMBLY IS ASSUMED TO LIE IN THE RANGE OF 100 TO 300 Hz. THE STRUCTURAL DAMPING FOR THE ASSEMBLY IS ASSUMED TO BE 15%, OR $g = .15$.

OBSERVING FROM TABLE 3 THAT THE MAXIMUM EXCITATION ACCELERATION, $\ddot{F}$, IN THE RANGE OF NATURAL FREQUENCIES OF THE SYSTEM IS:

$$\ddot{F} = 5g,$$

THE MAXIMUM RESPONSE ACCELERATIONS ARE THEN:

$$\ddot{y}_{max} = 5/g^2 = 5/(.015)^2 = 22.2\,g \text{ FOR ULTIMATE LOADINGS,}$$

AND $\ddot{y}_{max} = 14.8g$ FOR LIMIT LOADINGS.

AGAIN FROM HURTY AND RUBINSTEIN (REF. 2) THE RESPONSE OF A STRUCTURE MODELED AS A SINGLE DEGREE-OF-FREEDOM SYSTEM SUBJECTED TO A RANDOM EXCITATION, $\ddot{f}(t)$, IS GIVEN BY THE FOLLOWING FORMULA:

$$\overline{\ddot{y}^2(t)} = \frac{1}{2\pi}\int_0^\infty \ddot{y}(\Omega)\,d\Omega,$$

WHERE $\overline{\ddot{y}^2(t)}$ IS THE MEAN SQUARE RESPONSE ACCELERATION AND $\ddot{y}(\Omega)$ IS THE POWER SPECTRAL DENSITY FUNCTION OF THE RESPONSE ACCELERATION AND IS GIVEN BY:

$$\ddot{y}(\Omega) = |H(\Omega)|^2\,\ddot{f}(\Omega).$$

AS ABOVE $H(\Omega)$ IS THE SYSTEM MAGNIFICATION FACTOR. AND $\ddot{f}(\Omega)$ IS THE POWER SPECTRAL DENSITY FUNCTION OF THE RANDOM EXCITATION ACCELERATION.

MAINTAINING THE ASSUMPTION THAT THE NATURAL FREQUENCY OF THE SYSTEM FALLS IN THE RANGE OF 100 TO 300 Hz, THE EXCITATION ACCELERATION POWER SPECTRAL DENSITY FUNCTION IS:

$$\ddot{f}(\Omega) = .18\ g^2/Hz, \quad 100 < \Omega < 300.$$

THUS THE MEAN SQUARE RESPONSE ACCELERATION IS:

$$\overline{\ddot{y}^2(t)} = \frac{1}{2\pi}\int_{100}^{300} \frac{.18}{(.15)^2}\,d\Omega = \frac{4}{\pi}\,\Omega\Big|_{100}^{300} = \frac{(4)(200)}{\pi} = 255\ g^2.$$

THEREFORE THE ROOT MEAN SQUARE (1σ) RESPONSE ACCELERATION IS:

$$\sigma_{\ddot{y}} = \sqrt{\overline{\ddot{y}^2(t)}} = 16.0\ g.$$

THE STRUCTURE WILL BE DESIGNED TO WITHSTAND A 3σ, OR 48 g ACCELERATION LOAD.

CONSEQUENTLY THE GOVERNING LOADS FOR THE DESIGN OF THE BATTERY ASSEMBLY STRUCTURE ARE:

$$\ddot{y}_{max} \doteq 48\,g \text{ FOR ULTIMATE LOADING,}$$

AND $\quad \ddot{y}_{max} = 32\,g$ FOR LIMIT LOADING.

◦ <u>MATERIALS.</u> THIS SECTION OF THE REPORT PRESENTS THE PHYSICAL AND MECHANICAL PROPERTIES OF THE MATERIALS USED IN THE SAIS BATTERY ASSEMBLY STRUCTURE. THESE PROPERTIES WERE OBTAINED FROM MIL-HDBK-5A (REF. 3) AND ARE SUMMARIZED BELOW.

• <u>MAGNESIUM.</u> THE ANALYSIS PRESENTED IN THIS REPORT IS BASED ON USING MAGNESIUM ALLOY HM21A WITH A T8 HEAT TREATMENT FOR THE PLATES OF THE ASSEMBLY STRUCTURE. THIS ALLOY WAS SELECTED BECAUSE OF THERMAL CONSIDERATIONS. THE PROPERTIES OF HM21A-T8 ARE GIVEN IN TABLE 5.

• <u>ALUMINUM.</u> IT IS RECOMMENDED THAT ALUMINUM ALLOY 2024 WITH A T4 HEAT TREATMENT BE USED FOR THE THROUGH BOLTS AND TIE-DOWN BOLTS OF THE ASSEMBLY STRUCTURE. THIS RECOMMENDATION IS BASED ON THE KNOWN AVAILABILITY OF SUCH BOLTS. (THERE IS SOME DOUBTS AS TO THEIR AVALABILITY IN MAGNESIUM.) THE PROPERTIES OF THIS ALLOY ARE GIVEN IN TABLE 5.

TABLE 5. MATERIAL PROPERTIES

PROPERTY	Mg HM21A-T8	Al 2024-T4
E, psi	$6.5 \cdot 10^6$	$10.5 \cdot 10^6$
E_c, psi	$6.5 \cdot 10^6$	$10.7 \cdot 10^6$
G, psi	$2.4 \cdot 10^6$	$4.0 \cdot 10^6$
w, lb/in³ (pci)	.064	.100
F_{tu}, ksi	33	62
F_{ty}, ksi	18	40
F_{cy}, ksi	15	32
F_{su}, ksi	21	37
F_{sy}, ksi	12	24
F_{bru}, ksi	47	93
F_{bry}, ksi	29	63
e, %	6	10

• ESTIMATED WEIGHTS. THE FOLLOWING WEIGHT ESTIMATES ARE BASED ON ASSUMED PLATE THICKNESSES TAKEN FROM THE SUPPLIED RANGES OF SIZES. WEIGHTS OF THE MYLAR FILM, WIRING, etc. WERE SUPPLIED BY RON HAAS.

BATTERY CELL AND SUPPORT RIBS (5 EACH)

CELLS (4 AT .358 lbs)	1.432 lbs	
SUPPORT RIB WEB		
(8.00 in² x .03 in AT .064 pci) . .	.015	
SUPPORT RIB FLANGE		
(5.00 in² x .04 in AT .064 pci) . .	.013	
SUPPORT BLOCKS (3 AT .0007 lbs) .	.002	
MYLAR FILM	.008	
WIRING	.008	
PAINT	.005	
SUBTOTAL	1.483 lbs x 5 =	7.415 lbs

BATTERY END PLATE (2 EACH)

END PLATE FLANGE		
(8.80 in² x .03 in AT .064 pci) . .	.017 lbs	
END PLATE WEBS		
(6.45 in² x .06 in AT .064 pci) . .	.025	
BOLT SEATS		
(.56 in² x .375 in AT .064 pci) . .	.013	
CONNECTOR SEAT		
(.08 in² x .25 in AT .064 pci) . .	.001	
TIE-DOWN BOLT TAB		
(.38 in² x .04 in AT .064 pci) . .	.001	
CONNECTOR	.002	
PAINT	.006	
SUBTOTAL	.065 lbs x 2 =	.130 lbs

THROUGH BOLT (2 EACH)

.19 in ϕ x 11.0 in AT 0.1 lbs . . .	.031 lbs x 2 =	.062 lbs

BATTERY TOTAL WEIGHT (LESS TIE-DOWN BOLTS) . . . 7.607 lbs

• STRESS ANALYSIS. STRESS ANALYSIS WILL BE PERFORMED ON THE STRUCTURE OF THE SMS BATTERY ASSEMBLY BROKEN UP INTO FOUR COMPONENTS: BATTERY CELL SUPPORT RIBS, THROUGH BOLTS, BATTERY END PLATES, AND TIE-DOWN BOLTS. THE STRESS ANALYSIS FOR EACH OF THESE COMPONENTS IS PRESENTED IN THIS SECTION.

• BATTERY CELL SUPPORT RIBS. FOR THE PURPOSE OF SIZING THE WEB AND FLANGE OF THE SUPPORT RIB, EACH OF THE FIVE UNITS WILL BE ASSUMED TO RESPOND INDEPENDENTLY. THE CLAMPING EFFECT OF THE THROUGH BOLTS WILL BE NEGLECTED. DETAILS OF THE SUPPORT RIB ARE SHOWN IN THE SKETCH ON THE FOLLOWING PAGE.

ONE OF THE FOLLOWING LOADS GOVERNS THE THICKNESS OF THE WEB OF THE SUPPORT RIB:

1. ULTIMATE LOADING OF 48g IN Z-DIRECTION,
2. LIMIT LOADING OF 32g IN Z-DIRECTION,
3. ULTIMATE LOADING OF 48g IN X-DIRECTION,
4. LIMIT LOADING OF 32g IN X-DIRECTION.

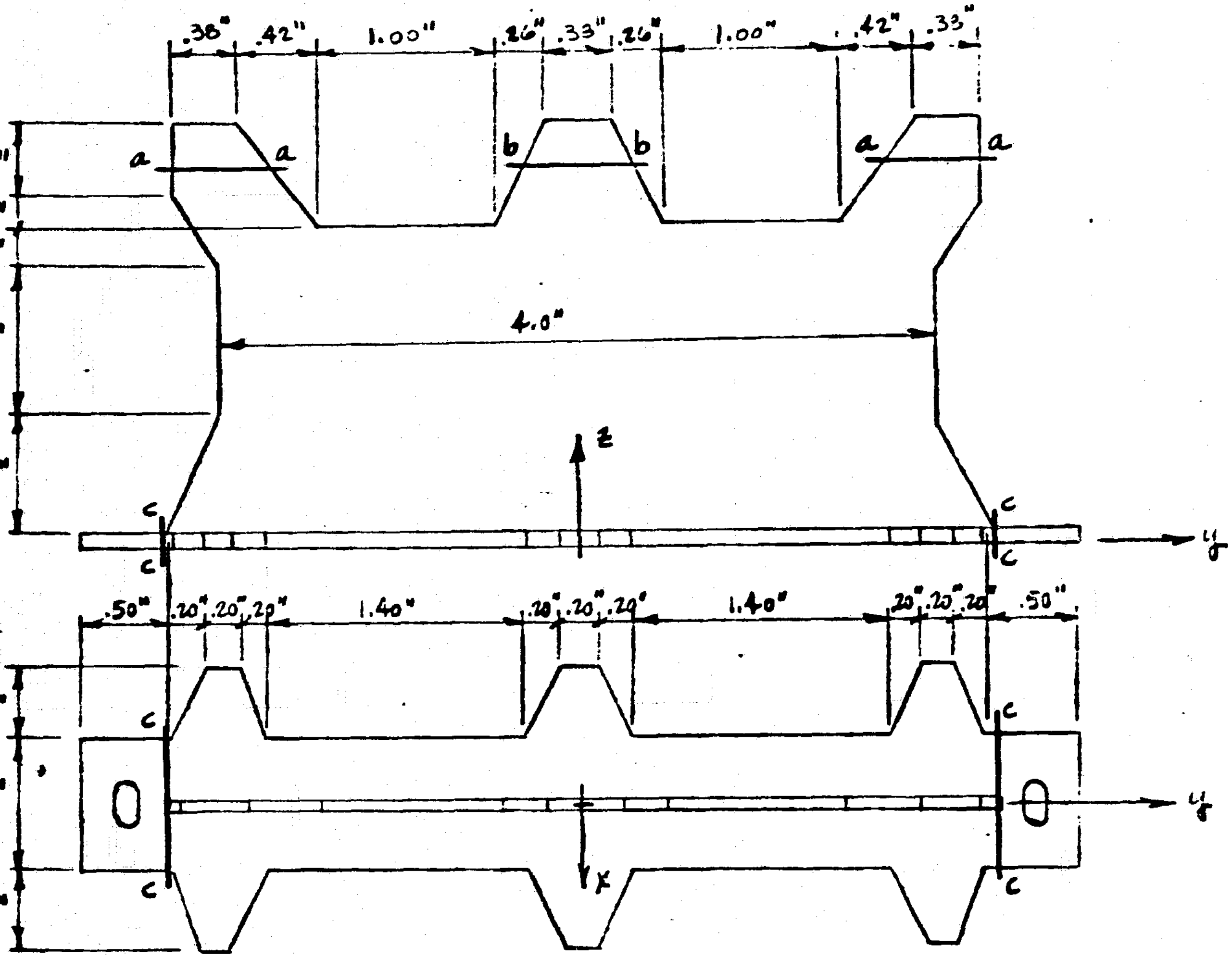
ASSUMING THAT THE SUPPORT BLOCKS LOCKING THE CELLS TO THE SUPPORT RIB TRANSFER THE LOADS IN THE Z-DIRECTION TO THE WEB, THE CRITICAL SECTIONS OCCUR AT THE EDGES OF THE SUPPORT BLOCKS. THESE SECTIONS ARE MARKED a-a AND b-b IN THE SKETCH ON THE FOLLOWING PAGE. THE TWO END SUPPORT BLOCKS ARE ASSUMED TO TRANSFER 50% OF THE TOTAL LOAD AND THE CENTER SUPPORT BLOCK TO TRANSFER THE OTHER 50%. THE LENGTH OF SECTION a-a IS .55 in AND THAT OF SECTION b-b IS .60 in. THUS SECTION b-b IS CRITICAL. ASSUMING THAT THE WEB IS .030 in THICK, THE AREA RESISTING THE LOAD IS .018 in². THE WEIGHT OF THE CELLS IS 1.432 lbs.

FOR THE ULTIMATE LOADING OF 48g, THE TENSILE STRESS IN THE WEB IS:

$$\sigma_t = \frac{P}{A} = \frac{(48)(1.432)}{.018} = 3.9 \text{ ksi} \ll 33 \text{ ksi}, \quad F.S = 8.46.$$

FOR THE LIMIT LOADING OF 32g, THE TENSILE STRESS IN THE WEB IS:

$$\sigma_t = \frac{P}{A} = \frac{(32)(1.432)}{.018} = 2.4 \text{ ksi} \ll 16 \text{ ksi}, \quad F.S. = 6.92.$$



SCALE: 1" = 1"

CELL SUPPORT RIB

-12-

THE LOADINGS IN THE X-DIRECTION ARE RESISTED BY THE WEB ACTING IN SHEAR, THE CRITICAL SECTION BEING AT THE FLANGE OF THE SUPPORT RIB. THE WEIGHT CONTRIBUTING TO THIS SHEAR LOAD IS 1.468 lbs. THE LENGTH OF THE WEB RESISTING THE LOAD IS 4.60 in. ASSUMING THE WEB IS .030 in THICK, THE SHEAR AREA IS .128 in².

FOR THE ULTIMATE LOADING OF 48 g, THE SHEAR STRESS IN THE WEB IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(48)(1.468)}{(2)(.128)} = 0.9 \text{ ksi} \ll 21 \text{ ksi}, \quad F.S. = 23.35.$$

FOR THE LIMIT LOADING OF 32 g, THE SHEAR STRESS IN THE WEB IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(32)(1.468)}{(2)(.128)} = 0.6 \text{ ksi} \ll 12 \text{ ksi}, \quad F.S. = 20.00.$$

THUS A WEB THICKNESS OF .030 in IS ADEQUATE.

THE THICKNESS OF THE FLANGE OF THE SUPPORT RIB IS GOVERNED BY BENDING OR SHEAR STRESS DUE TO LOADINGS IN THE Z-DIRECTION OR BY BEARING STRESS OF THE TIE-DOWN BOLTS DUE TO LOADINGS IN THE X-DIRECTION.

THE CRITICAL SECTIONS OF THE FLANGE IN BENDING AND SHEAR ARE MARKED C-C IN THE SKETCH ON THE PREVIOUS PAGE. THE LOADS ARE DETERMINED BY ASSUMING THE RIB TO BE A BEAM PINNED AT THE CENTERLINES OF THE TIE-DOWN BOLTS. THE SHEAR LOAD IS THUS ONE-HALF THE TOTAL LOAD AND THE BENDING MOMENT IS THIS LOAD WITH A LEVER ARM OF .25 in. THE LENGTH OF SECTION C-C IS .75 in. AND ASSUMING THAT THE FLANGE IS .040 in THICK THE SHEAR AREA IS .03 in² AND THE MOMENT OF INERTIA OF THE SECTION IS $4.0 \cdot 10^{-6}$ in⁴. THE WEIGHT CONTRIBUTING TO THE LOADING IS 1.483 lbs.

FOR AN ULTIMATE LOADING OF 48 g IN THE Z-DIRECTION, THE SHEAR STRESS IN THE FLANGE IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(48)(.5)(1.483)}{(2)(.03)} = 1.8 \text{ ksi} \ll 21 \text{ ksi}, \quad F.S. = 11.65,$$

AND THE BENDING STRESS IS:

$$\sigma_b = \frac{Mc}{I} = \frac{(48)(.5)(1.488)(.25)(.02)}{4.0 \cdot 10^{-6}} = 44.6 \text{ ksi} > 33 \text{ ksi}, \quad F.S. = 0.74.$$

THUS THE FLANGE THICKNESS MUST BE INCREASED. TRY A THICKNESS OF .055 in. THE MOMENT OF INERTIA IS THEN $10.4 \cdot 10^{-6}$ in^4. THE BENDING STRESS FOR THE SAME ULTIMATE LOADING IS:

$$\sigma_b = \frac{Mc}{I} = \frac{(48)(.5)(1.488)(.25)(.0275)}{10.4 \cdot 10^{-6}} = 23.6 \text{ ksi} < 33 \text{ ksi}, \quad F.S. = 1.40.$$

FOR A LIMIT LOADING OF 32g IN THE Z-DIRECTION, THE SHEAR STRESS IN THE FLANGE IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(32)(.5)(1.488)}{(2)(.04125)} = 0.9 \text{ ksi} \ll 12 \text{ ksi}, \quad F.S. = 13.35,$$

AND THE BENDING STRESS IS:

$$\sigma_b = \frac{Mc}{I} = \frac{(32)(.5)(1.488)(.25)(.0275)}{10.4 \cdot 10^{-6}} = 15.8 \text{ ksi} < 18 \text{ ksi}, \quad F.S. = 1.14.$$

ASSUMING THAT THE TIE-DOWN BOLTS ARE .19 in IN DIAMETER, THE BEARING AREA OF THE FLANGE RESISTING THE LOADINGS IN THE X-DIRECTION IS .010 in^2. THE WEIGHT CONTRIBUTING TO THE LOADING IS 1.488 lbs AND EACH BEARING AREA RESISTS ONE-HALF THE TOTAL LOAD.

FOR AN ULTIMATE LOADING OF 48g IN THE X-DIRECTION, THE BEARING STRESS ON THE SUPPORT RIB FLANGE IS:

$$\sigma_{br} = \frac{P}{A} = \frac{(48)(.5)(1.488)}{.010} = 3.6 \text{ ksi} \ll 47 \text{ ksi}, \quad F.S. = 13.05.$$

FOR A LIMIT LOADING OF 32g IN THE X-DIRECTION, THE BEARING STRESS ON THE FLANGE IS:

$$\sigma_{br} = \frac{P}{A} = \frac{(32)(.5)(1.488)}{.010} = 2.4 \text{ ksi} \ll 29 \text{ ksi}, \quad F.S. = 12.10.$$

<u>THUS A FLANGE THICKNESS OF .055 in IS ADEQUATE.</u>

ORIGINAL PAGE IS OF POOR QUALITY

• <u>THROUGH BOLTS.</u> THE SIZE OF THE THROUGH BOLTS IS DETERMINED BY THE TENSILE STRESS DEVELOPED BY THE TORQUE APPLIED TO THE BOLT OR BY THIS STRESS PLUS THE TENSILE STRESS DUE TO THE LOAD CAUSED BY THE FAILURE OF A BATTERY CELL. FROM REFERENCE 4, THE BOLT TENSILE FORCE, P, IS GIVEN BY THE FOLLOWING FORMULA:

$$P = \frac{T}{KD},$$

WHERE T IS THE APPLIED TORQUE IN in-lb., K IS THE TORQUE COEFFICIENT, AND D IS THE NOMINAL BOLT DIAMETER IN in.

THE TORQUE COEFFICIENT, K, WITH NORMALLY DRY SURFACES AND NORMAL UNLUBRICATED BOLT AND NUT USUALLY HAS A VALUE OF ABOUT 2.0.

ASSUMING A 10-32 ALUMINUM (2024-T4) BOLT ($D = .19$ in, $A_s = .02$ in^2) AND AN APPLIED TORQUE OF 15 in-lb., THE BOLT TENSILE FORCE IS:

$$P = \frac{15}{(.2)(.19)} = 400 \text{ lb.}$$

THE TENSILE STRESS IS THEN:

$$\sigma_t = \frac{P}{A_s} = \frac{400}{.02} = 20.0 \text{ ksi} < 40 \text{ ksi}, \quad F.S. = 2.0.$$

ASSUMING THAT THE ENTIRE LOAD DUE TO A CELL FAILURE ($p = 250$ psi ON AN AREA, $A = 4$ in^2, OR $P = 1000$ lbs) GOES INTO ONE BOLT, THE LOAD ON THE BOLT IS THEN 1400 lbs AND THE TENSILE STRESS IS:

$$\sigma_t = \frac{P}{A_s} = \frac{1400}{.02} = 70.0 \text{ ksi} > 62 \text{ ksi}, \quad F.S. = 0.89.$$

THUS A 10-32 BOLT IS INADEQUATE. TRY A 12-28 ALUMINUM (2024-T4) BOLT ($D = .216$ in, $A_s = .0258$ in^2). FOR THE ULTIMATE LOAD OF 1400 lbs, THE TENSILE STRESS IS:

$$\sigma_t = \frac{P}{A_s} = \frac{1400}{.0258} = 54.3 \text{ ksi} < 62 \text{ ksi}, \quad F.S. = 1.14.$$

FOR THE LIMIT LOAD OF 400 lbs, THE TENSILE STRESS IS:

$$\sigma_t = \frac{P}{A_s} = \frac{400}{.0258} = 15.5 \text{ ksi} < 40 \text{ ksi}, \quad F.S. = 2.58.$$

<u>THUS A 12-28 ALUMINUM 2024-T4 BOLT IS ADEQUATE.</u>

• BATTERY END PLATE. THE BATTERY END PLATE IS DESIGNED TO WITHSTAND EITHER THE LOADS INDUCED BY THE CLAMPING ACTION OF THE THROUGH BOLTS AND THE RESISTANCE OF THE BATTERY CELLS TO THIS CLAMPING ACTION, OR THESE LOADS PLUS THE LOADS RESULTING FROM A FAILURE OF A BATTERY CELL. THE END PLATE IS COMPOSED OF VARIOUS COMPONENTS: FACE FLANGE (PARALLEL TO y-z PLANE), MAIN SUPPORT WEB (PARALLEL TO x-y PLANE), SIDE WEBS (PARALLEL TO x-z PLANE), THROUGH BOLT SEAT BLOCKS, CONNECTOR SEAT BLOCKS, AND TIE-DOWN BOLT TAB (SIZED THE SAME AS THE CELL SUPPORT RIB FLANGE). DETAILS OF THE BATTERY END PLATE ARE SHOWN IN THE SKETCH ON THE FOLLOWING PAGE. FROM ABOVE THE FORCE IN EACH THROUGH BOLT IS 400 lbs OR THE FORCE IN ONE BOLT IS 1400 lbs WITH 400 lbs IN THE OTHER. THE COMPONENTS WILL BE DESIGNED SO THAT ALLOWABLE YIELD STRESSES ARE NOT EXCEEDED UNDER THE TORQUE LOAD AND SO THAT ULTIMATE STRESSES ARE NOT EXCEEDED UNDER THE CELL FAILURE LOAD PLUS THE TORQUE LOAD.

THE FACE FLANGE IS SIZED ASSUMING THAT 20% OF THE CLAMPING FORCE IS UNIFORMLY DISTRIBUTED OVER ITS AREA. THIS IS CONSERVATIVE SINCE MOST OF THE LOAD WILL BE CARRIED BY THE WEBS OF THE END PLATE AND SINCE THE STRENGTH OF THE WALLS OF THE BATTERY CELLS WILL BE NEGLECTED. THE RESULTING UNIFORMLY DISTRIBUTED PRESSURE, p, IS 20 psi. THE CRITICAL AREA IS BOUNDED BY LINES CONNECTING POINTS a, b, c, AND d IN THE SKETCH ON THE PREVIOUS PAGE. ASSUMING THAT THIS AREA IS A FLAT PLATE FIXED ON THREE EDGES AND FREE ON THE FOURTH. THE FOLLOWING FORMULAS FROM REFERENCE 5 GIVE THE MAXIMUM BENDING MOMENT AND DEFLECTION OCCURRING IN THE PLATE:

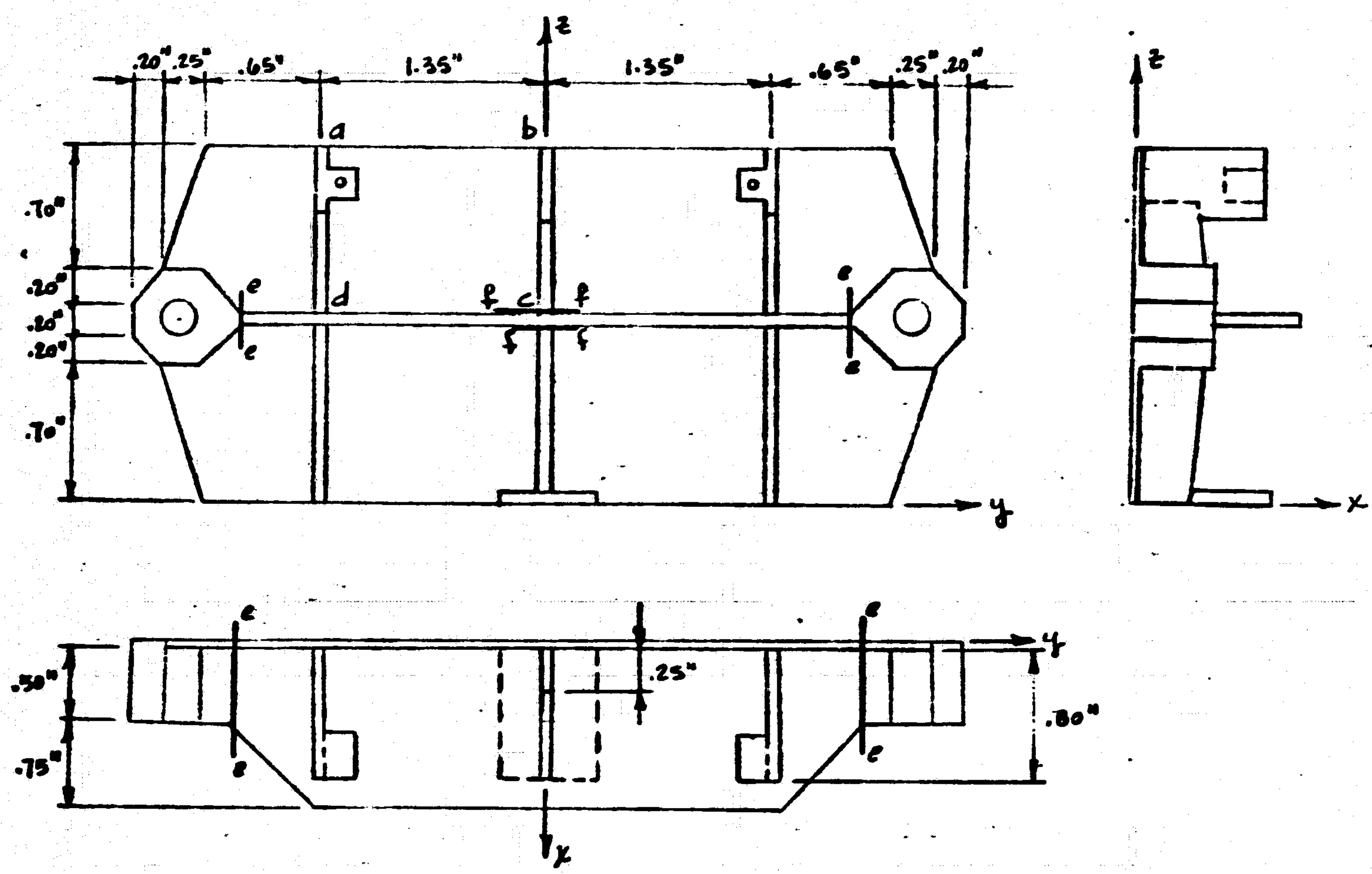
$$M_{max} = .0857\, pa^2,$$

AND

$$w_{max} = .00341 \frac{pa^4}{D},$$

WHERE a IS THE LENGTH OF THE SHORT SIDE AND D IS THE FLEXURAL RIGIDITY OF THE PLATE AND IS GIVEN BY:

$$D = \frac{Et^3}{12(1-\nu^2)}.$$



SCALE: 1" = 1"

BATTERY END PLATE

THE MAXIMUM STRESS IS GIVEN BY:

$$\sigma_{max} = \frac{6 M_{max}}{t^2} .$$

FOR THIS PLATE AND MATERIAL:

$$a = 1.0 \text{ in} , \quad E = 6.5 \cdot 10^6 \text{ psi} , \quad \nu = .35 ,$$

ASSUMING THAT THE FLANGE IS .025 in THICK, THE FLEXURAL RIGIDITY IS:

$$D = \frac{(6.5 \cdot 10^6)(.025)^3}{(12)[1-(.35)^2]} = 9.53 \text{ lb-in.}$$

THE MAXIMUM STRESS IS:

$$\sigma_{max} = \frac{(6)(.0857)(20)(1)^2}{(.025)^2} = 16.5 \text{ ksi} < 18 \text{ ksi} ,$$

AND THE MAXIMUM DEFLECTION IS:

$$w_{max} = \frac{(.00341)(20)(1)^4}{9.53} = .007 \text{ in} < .010 \text{ in ALLOWABLE.}$$

<u>THUS A FACE FLANGE THICKNESS OF .025 in IS ADEQUATE.</u>

THE SIZE OF THE MAIN SUPPORT WEB IS DETERMINED BY ONE OF THE TWO FOLLOWING REQUIREMENTS: (1) THE ABILITY TO CARRY THE LOAD FROM THE THROUGH BOLT SEAT BLOCK IN SHEAR THROUGH SECTION e-e (SHOWN ON SKETCH ON PAGE 17), OR (2) THE ABILITY TO CARRY THE LOAD WHEN ACTING AS A SIMPLE BEAM (NEGLECTING THE SIDE WEBS).

ASSUMING THAT THE THROUGH BOLT SEAT BLOCK IS .50 in LONG AND THAT THE WEB IS .225 in THICK, THE SHEAR AREA IS .0112 in^2.

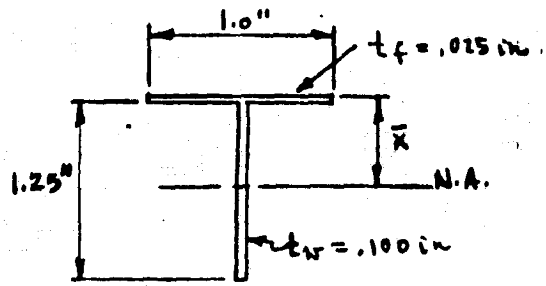
FOR THE TORQUE LOAD (P = 400 lbs) THE SHEAR STRESS IN THE WEB IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(400)}{(2)(.112)} = 5.4 \text{ ksi} < 12 \text{ ksi} , \quad F.S = 2.22 .$$

FOR THE TORQUE LOAD PLUS THE CELL FAILURE LOAD (P = 1400 lbs), THE SHEAR STRESS IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(1400)}{(2)(.112)} = 18.8 \text{ ksi} < 21 \text{ ksi} , \quad F.S. = 1.12 .$$

ASSUMING THAT THE MAIN SUPPORT WEB IS .100 in THICK BETWEEN THE SIDE WEBS, THE MOMENT OF INERTIA OF THE WEB ACTING AS A BEAM IS CALCULATED BELOW.



$$\bar{x} = \frac{(1.0)(.025)(.0125) + (1.25)(.1)(.65)}{(1.0)(.025) + (1.25)(.1)}$$

$$\bar{x} = \frac{.0816}{.15} = .544 \text{ in.}$$

$$I = \frac{(.1)(1.25)^3}{12} + (1)(.025)(.531)^2 + (1.25)(.1)(.106)^2$$

$$I = .0247 \text{ in}^4$$

THE CLAMPING LOAD UNIFORMLY DISTRIBUTED OVER THE 4.0 in LENGTH OF THE WEB GIVES A LOAD, $w = (2)(400)/4 = 200$ lb/in. THE RESULTING MAXIMUM BENDING MOMENT AND STRESS ARE:

$$M_{max} = \frac{wL^2}{8} = \frac{(200)(4)^2}{8} = 400 \text{ in-lb,}$$

AND $$\sigma_{max} = \frac{Mc}{I} = \frac{(400)(.731)}{.0247} = 11.9 \text{ ksi} < 18 \text{ ksi}, \quad F.S. = 1.51.$$

THE CLAMPING LOAD PLUS THE CELL FAILURE LOAD UNIFORMLY DISTRIBUTED OVER THE WEB GIVES A LOAD, $w = 1800/4 = 450$ lb/in. THE RESULTING MAXIMUM BENDING MOMENT AND STRESS ARE:

$$M_{max} = \frac{wL^2}{8} = \frac{(450)(4)^2}{8} = 900 \text{ in-lb.}$$

AND $$\sigma_{max} = \frac{Mc}{I} = \frac{(900)(.731)}{.0247} = 26.6 \text{ ksi} < 33 \text{ ksi}, \quad F.S. = 1.24.$$

<u>THUS A MAIN SUPPORT WEB THICKNESS OF .225 in ADJACENT TO THE BOLT SEATS AND OF .100 in BETWEEN THE SIDE WEBS IS ADEQUATE.</u>

THE SIZE OF THE SIDE WEBS IS DETERMINED BY THE REQUIREMENT THAT THE WEBS CARRY THE UNIFORMLY DISTRIBUTED CLAMPING LOAD TO THE MAIN SUPPORT WEB IN SHEAR ACROSS SECTION f-f (SHOWN ON THE SKETCH ON PAGE 17). THE CONTRIBUTING AREA OF LOAD IS 1.0 in X 1.35 in, OR 1.35 in² AND THE LOAD IS 100 psi. THUS THE SHEAR LOAD, P, TO BE CARRIED IS 135 lbs. ASSUMING THE WEB IS .025 in THICK, THE SHEAR AREA TRANSMITTING THE LOAD IS .029 in².

THE SHEAR STRESS IS:

$$\sigma_s = \frac{3P}{2A} = \frac{(3)(135)}{(2)(.020)} = 10.1 \text{ ksi} < 12 \text{ ksi}, \quad F.S. = 1.19.$$

THUS A SIDE WEB THICKNESS OF .025 in IS ADEQUATE.

THE THROUGH BOLT SEAT BLOCK IS NOMINALLY SIZED AS .500 in LONG.

THE CONNECTOR SEAT BLOCK IS NOMINALLY SIZED AS .250 in LONG.

• TIE-DOWN BOLTS. THE TIE-DOWN BOLTS ARE SIZED TO RESIST THE FOLLOWING TWO LOADINGS IN BOTH TENSION AND SHEAR CONSIDERING THE ENTIRE BATTERY ACTING AS A UNIT (WITH TEN BOLTS ACTING) OR CONSIDERING EACH CELL ASSEMBLY ACTING AS A UNIT (WITH TWO BOLTS ACTING ON EACH).

1. ULTIMATE LOADING OF 48 g,
2. LIMIT LOADING OF 32 g.

THE WEIGHT OF THE BATTERY ASSEMBLY IS 7.646 lbs AND THAT OF EACH CELL ASSEMBLY IS 1.488 lbs. THE MAXIMUM BOLT LOAD (IN BOTH TENSION AND SHEAR) IS THE GREATER OF THE TWO FOLLOWING LOADS:

$$P_1 = \frac{7.646}{10} (g \text{ LOADING}) = .7646 (g \text{ LOADING}),$$

OR

$$P_2 = \frac{1.488}{2} (g \text{ LOADING}) = .744 (g \text{ LOADING}).$$

THUS THE MAXIMUM ULTIMATE LOADING IS 36.7 lbs AND THE MAXIMUM LIMIT LOADING IS 24.5 lbs.

FROM REFERENCE 4, THE TENSILE LOAD, P_t, AND THE SHEAR LOAD, P_s, WHICH A BOLT CAN CARRY ARE GIVEN BY THE FOLLOWING FORMULAS:

$$P_t = \sigma_t A_s,$$

AND

$$P_s = \sigma_s A_r,$$

WHERE σ_t IS THE ALLOWABLE TENSILE STRESS, A_s IS THE TENSILE STRESS AREA, σ_s IS THE ALLOWABLE SHEAR STRESS, AND A_r IS THE SHEAR STRESS AREA.

ASSUMING THAT THE TIE-DOWN BOLTS ARE ALUMINUM 2024-T4 10-32 BOLTS, THE FOLLOWING DATA WAS OBTAINED FROM REFERENCE 4:

$$A_s = .0200 \text{ in}^2,$$

AND $$A_r = .0175 \text{ in}^2.$$

FOR THE ULTIMATE LOADING OF 36.7 lbs, THE TENSILE AND SHEAR STRESSES ARE:

$$\sigma_t = \frac{P_t}{A_s} = \frac{36.7}{.0200} = 1.9 \text{ ksi} \ll 33 \text{ ksi}, \quad F.S. = 17.45,$$

AND $$\sigma_s = \frac{P_s}{A_r} = \frac{36.7}{.0175} = 2.1 \text{ ksi} \ll 21 \text{ ksi}, \quad F.S. = 10.00.$$

FOR THE ULTIMATE LOADING OF 24.5 lbs, THE TENSILE AND SHEAR STRESSES ARE:

$$\sigma_t = \frac{P_t}{A_s} = \frac{24.5}{.0200} = 1.3 \text{ ksi} \ll 18 \text{ ksi}, \quad F.S. = 13.85,$$

AND $$\sigma_s = \frac{P_s}{A_r} = \frac{24.5}{.0175} = 1.4 \text{ ksi} \ll 12 \text{ ksi}, \quad F.S. = 8.58.$$

THUS THE TIE-DOWN BOLTS ARE SIZED AS 10-32 ALUMINUM 2024-T4 BOLTS.

• FINAL DESIGN WEIGHT. THE FOLLOWING WEIGHTS ARE BASED ON THE FINAL DESIGN SIZINGS.

BATTERY CELLS AND SUPPORT RIB (5 EACH		
CELLS (4 AT .358 lbs)	1.432 lbs	
SUPPORT RIB WEB		
($8.00\ in^2$ X .03 in AT .064 pci)	.015	
SUPPORT RIB FLANGE		
($5.00\ in^2$ X .055 in AT .064 pci)	.018	
SUPPORT BLOCKS (3 AT .0007 lbs)	.002	
MYLAR FILM	.008	
WIRING	.008	
PAINT	.005	
SUBTOTAL	1.488 lbs X 5 =	7.440 lbs
BATTERY END PLATE (2 EACH)		
END PLATE FLANGE		
($8.80\ in^2$ X .025 in AT .064 pci)	.014 lbs	
END PLATE MAIN SUPPORT WEB		
($3.38\ in^2$ X .100 in AT .064 pci)	.022	
($0.88\ in^2$ X .150 in AT .064 pci)	.013	
END PLATE SIDE WEBS		
($3.00\ in^2$ X .025 in AT .064 pci)	.005	
THROUGH BOLT SEATS		
($.56\ in^2$ X .50 in AT .064 pci)	.018	
CONNECTOR SEATS		
($.08\ in^2$ X .25 in AT .064 pci)	.001	
TIE-DOWN BOLT TAB		
($.38\ in^2$ X .055 in AT .064 pci)	.001	
CONNECTOR	.002	
PAINT	.006	
SUBTOTAL	.082 lbs X 2 =	.164 lbs
THROUGH BOLT (2 EACH)		
.216 in ϕ X 11.0 in AT .100 pci	.037 lbs X 2 =	.074 lbs
TOTAL BATTERY WEIGHT (LESS TIE-DOWN BOLTS)		7.678 lbs

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APPENDIX D

SMS BATTERY THERMAL ANALYSIS

PHILCO

Intra Company

21 May 1971
TS-151
SMS-PCC 1650

To: R. J. Haas

From: A. H. Sato

Subject: SMS Battery Thermal Analysis

SUMMARY

Thermal analyses were performed to determine steady state temperature gradients within the SMS battery assembly when mounted to constant temperature baseplates of 35°C, 20°C and 5°C. The radiant heat transfer environment was assumed to be the equivalent sink temperature of the spacecraft for the synchronous equinox orbit. For the spacecraft with adiabatic end shields, the sink temperature was 16°C.

The maximum gradient between the baseplate and cells for baseplate temperatures of 35°C, 20°C and 5°C were 2C°, 3C° and 4C° respectively.

An additional case was studied where the cell support rib wall thickness was increased from 0.030 inches to 0.040 inches. A maximum gradient of 2C° was computed for a baseplate temperature of 20°C.

OBJECTIVE AND CONDITIONS OF ANALYSIS

The objective of the analysis was to determine steady state temperature gradients between battery cells and baseplate when the latter was held at constant temperatures of 35°C, 20°C and 5°C.

Conditions of the Analysis

- The radiant environment was assumed to be the equivalent spacecraft sink temperature for the synchronous equinox orbit. For the spacecraft with adiabatic end shields the sink temperature was 16°C.

- At the joint between the cell support ribs and the baseplate (see Figure 1), it was assumed that an interface compound was used with a joint conductance of 1000 BTU/hr-ft^2-$^{\circ}$F.

- The battery dissipated a total of 9 watts. Each of the 20 cells dissipated 0.45 watts. The heat was assumed to be uniformly distributed at all walls up to a height of 1.7 inches. (The actual cell casing height was 2 inches.) This was based on information received from the cognizant equipment engineer with regard to the internal construction of the cells.

DISCUSSION

The SMS battery analyzed consisted of 20 cells arranged in 2 rows. (See Figure 1.) The cell casing material was stainless steel 304 (thermal conductivity, K = 9.4 BTU/hr-ft-$^{\circ}$F). Between each pair of cells was a cell support rib. (See Figure 2.) The material assumed for support ribs and end plates was magnesium HM-21A (K = 79 BTU/hr-ft-$^{\circ}$F). A 1-mil mylar sheet (K = 0.1 BTU/hr-ft-$^{\circ}$F) was inserted at the cell-to-end plate, cell-to-cell and cell-to-support rib interfaces.

Since the battery was symmetrical, it was only necessary to analyze a quarter section of it. The other three-quarters would have similar temperature profiles. The nodal division of the quarter section analyzed is presented in Figure 3.

RESULTS

Temperature profiles were obtained for the cases where the baseplate was held constant at 35°C, 20°C, and 5°C. In addition, one case was studied where the support rib wall thickness was increased from 0.030 inches to 0.040 inches at a baseplate temperature of 20°C. The results of these four cases are presented in Table I.

The maximum gradients between cell and baseplate are 2C°, 3C° and 4C° for the first three cases, respectively, and 2C° for case 4. As was to be expected, the maximum gradients occurred in the center of the battery (cell 5). The minimum gradients occurred in the cells next to the end plate.

Of the 9 watts dissipated in the battery, 41% was conducted to the baseplate in case 1, 83% in case 2 and 84% in case 4. In case 3 all 9 watts and an additional 1.9 watts which were absorbed from the warmer radiant environment were transferred to the constant temperature baseplate.

With regard to thickening the cell support rib walls, it is seen from the temperature data of cases 2 and 4 and from the comparison of percent heat conducted to the baseplate that only a small improvement was gained in this fashion.

A H Sato

A. H. Sato

AHS:gb

cc: D. Briggs
A. Calimbas
W. Dobley
R. Robinson
W. Schmidt
C. Zierman

FIGURE 1
SMS 20-CELL BATTERY

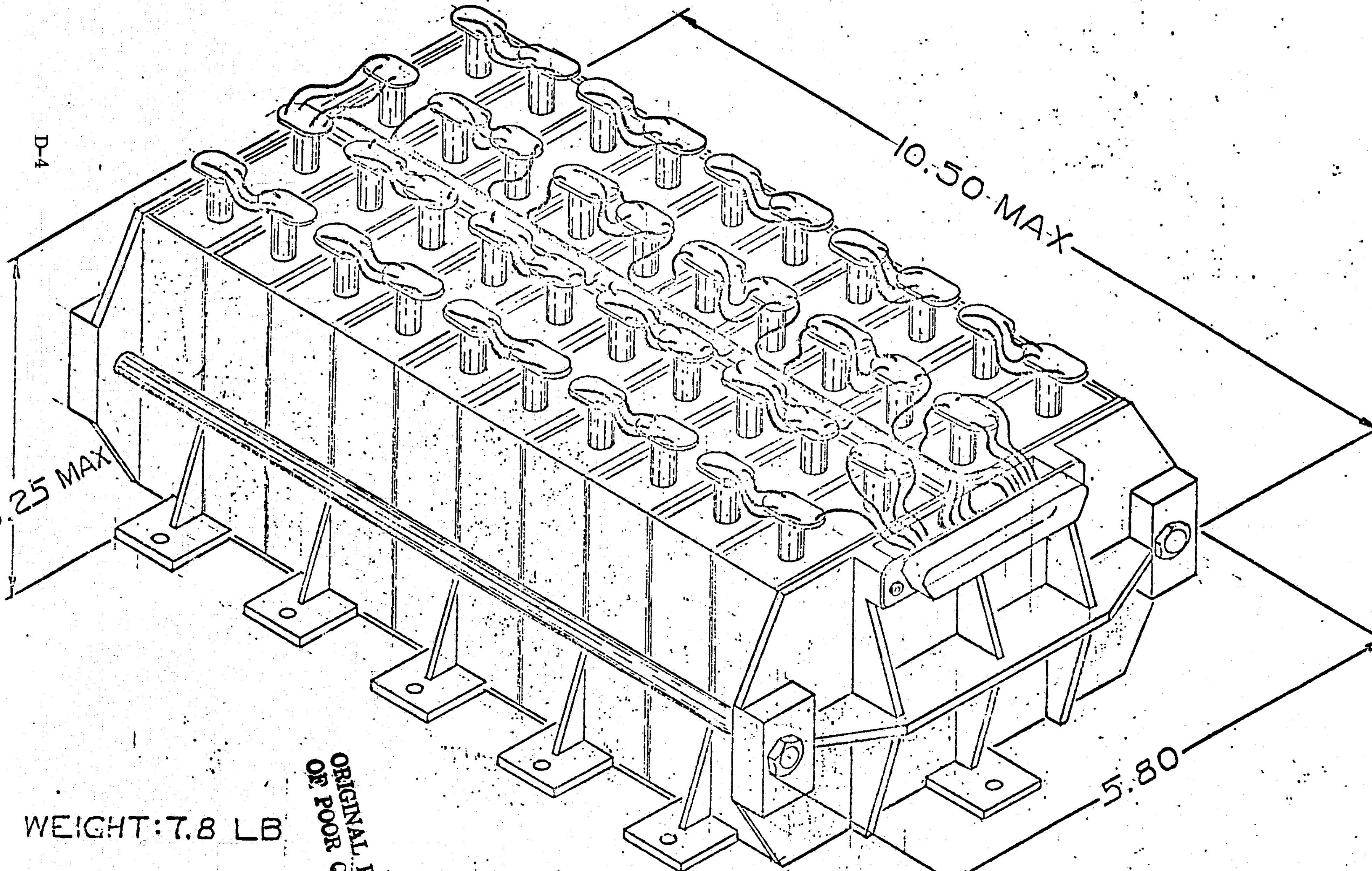


FIGURE 2
CELL AND CELL SUPPORT RIB ARRANGEMENT

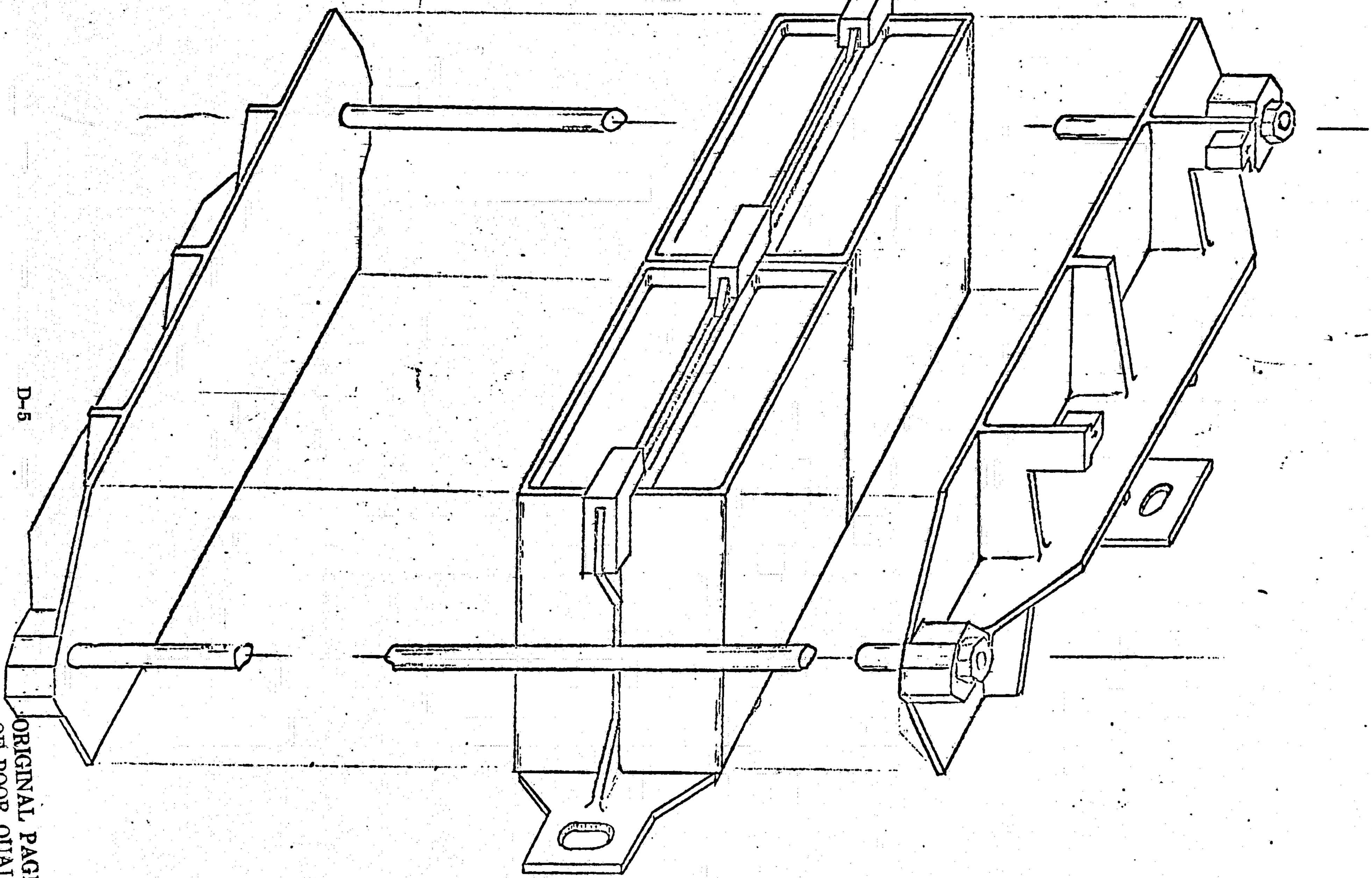
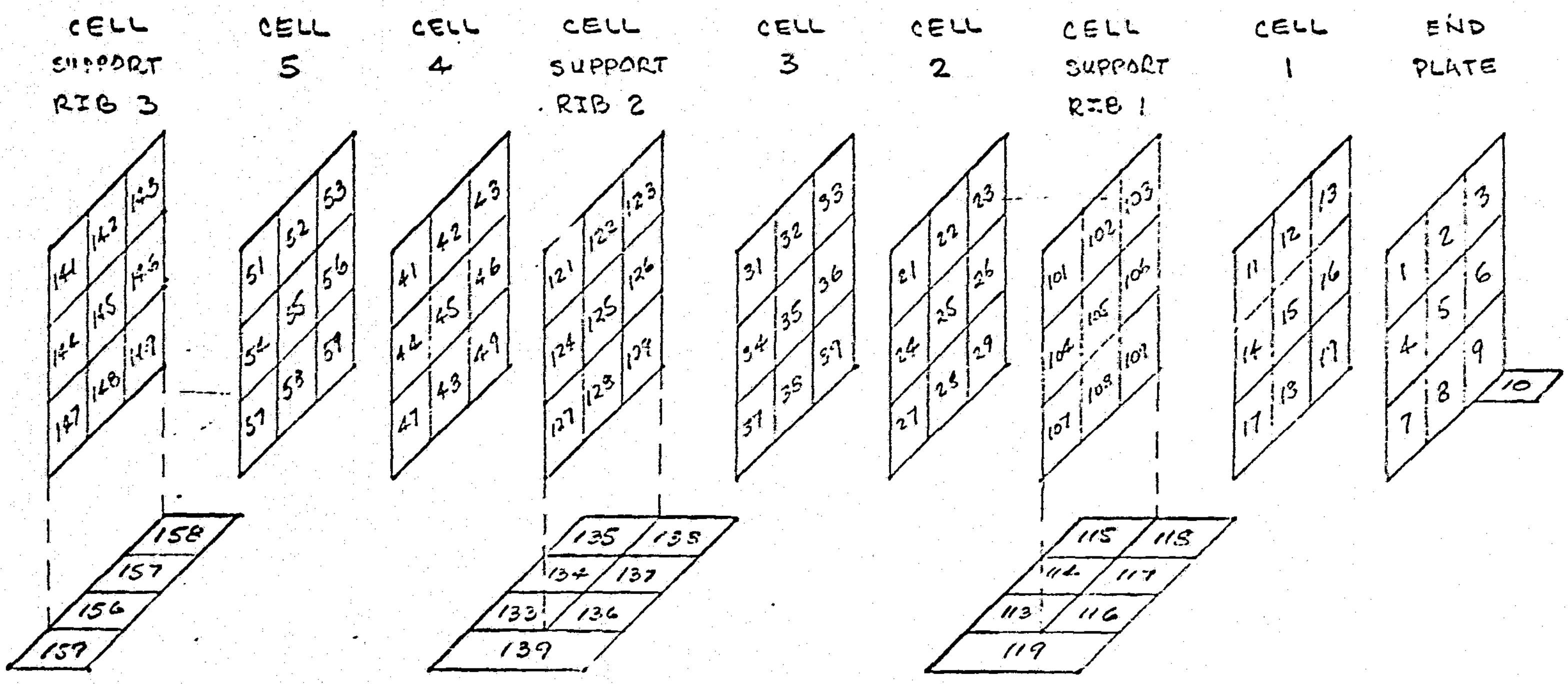


FIGURE 3.

SMS BATTERY THERMAL MODEL



NODE 200 ~ BASE PLATE
NODE 201 ~ RADIANT SINK

TABLE I

SMS BATTERY TEMPERATURES (°C)

	Case 1		Case 2		Case 3		Case 4[1]	
	Max	Min	Max	Min	Max	Min	Max	Min
Baseplate	35		20		5		20	
Radiant Sink	16		16		16		16	
Cell 1	36	35	22	21	9	7	22	21
Cell 2	36	35	22	21	9	7	22	21
Cell 3	36	35	22	21	9	7	22	21
Cell 4	37	35	23	21	9	7	22	21
Cell 5	37	35	23	21	9	5	22	20
End Plate	35	35	22	20	9	5	22	20
Rib 1	36	35	22	20	8	5	22	20
Rib 2	36	35	22	20	9	5	22	20
Rib 3	36	35	22	20	9	5	22	20
Maximum Gradient Cell-to-Base	+2C°		+3C°		+4C°		+2C°	

Notes: (1) Cell support rib wall thickness increased to 0.040 inches.

APPENDIX E

SMS BATTERY CELL PROCUREMENT SPECIFICATION SP-212064

PHILCO Ford

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303
FMC 11530

SPECIFICATION NO.

SP-212064C
Amendment #1

SMS
NICKEL-CADMIUM BATTERY CELL
(3.0 AMPERE HOUR)
PROCUREMENT SPECIFICATION

This Amendment forms a part of Specification SP-212064C, dated June 21, 1972.

So much of paragraph 3.1.5.1 as read ". . . 304L." is amended to read ". . . 304 or 304L."

PROGRAM SMS	PRIME CONTRACT NUMBER NAS 5-21575
Spec. Engr. [signature] Date 5-22-73	SRB Chairman [signature] 24 Aug 73
Resp. Engr. [signature] Date 8/22/73	Program Office [signature] Date 27 Aug 73
Quality Assurance [signature] 8-23-73	
Subsystem Manager DC Briggs 8-23-73	
System Engineering Barry T. Smith 8/23/73	
Test Engineering [signature] 8/23/73	
	Release Date ENGR DATA AUG 27 1973 Page 1 of 1

WDL 572A (1-72)

PHILCO

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303

SPECIFICATION NO.

SP-212064C

TITLE NICKEL-CADMIUM BATTERY CELL (3.0 AMPERE HOUR)

PROCUREMENT SPECIFICATION

PROGRAM/SITE SMS

PRIME CONTRACT NUMBER NAS5-21575

WDL APPROVAL:

PREPARED BY

Date

SUBSYSTEM MANAGER

L. P. Faber, Jr. Date 5/17/72

TEST ENGINEERING

D. J. McBrady Date 5/18/72

D. J. McBrady

CCB CHAIRMAN

Date 19 MAY 72

SMS PROGRAM OFFICE

J. Savides Date 6/2/72

J. Savides
Technical Director

NASA GSFC APPROVAL:

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SMS SPACECRAFT MANAGER

Date

Peter T. Burr

Release Date 7-13-72 DATA BANK

ENGR DATA AUG 02 1973

Page 1 of 65

WDL-872A (8-69)

PHILCO

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303

SPECIFICATION NO.
SP-212064C

TITLE NICKEL-CADMIUM BATTERY CELL (3.0 AMPERE HOUR)

PROCUREMENT SPECIFICATION

PROGRAM/SITE SMS

PRIME CONTRACT NUMBER NAS5-21575

WDL APPROVAL:	NASA GSFC APPROVAL:
PREPARED BY Date	
SUBSYSTEM MANAGER L. P. Faber, Jr. Date 5/17/2	
TEST ENGINEERING D. McBrady Date 5/18/72 D. J. McBrady	
CCB CHAIRMAN Date 19 MAY 72	ORIGINAL PAGE IS OF POOR QUALITY
SMS PROGRAM OFFICE Date 6/2/72 J. Savides Technical Director	SMS SPACECRAFT MANAGER Date Peter T. Burr

WDL-672A (8-69)

Release Date 7-13-72 DATA BANK

ENGR DATA AUG 02 1973

Page 1 of 65

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. SCOPE

1.1 General.- This specification defines performance, design, inspection, and test requirements for a hermetically sealed nickel-cadmium battery cell.

2. APPLICABLE DOCUMENTS

The following documents, of the issue noted, constitute a part of this specification to the extent specified herein. Should a conflict exist, this specification shall govern:

SPECIFICATIONS

Federal

QQ-S-766	Steel, Plate and Strip, Corrosion Resisting

Military

MIL-R-5031B	Rod and Wire, Welding, Corrosion and Heat Resistant Alloys
MIL-W-8611A	Welding, Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys Process for
MIL-F-14072	Finishes for Ground Signal Equipment
MIL-C-45662A	Calibration System Requirements

STANDARDS

Military

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-129D	Marking for Shipment and Storage
MIL-STD-130C	Identification Marking of U.S. Military Property

NOTE: Verticle Line in Margin indicates change in this issue.

2. APPLICABLE DOCUMENTS (continued)

STANDARDS

Military

MIL-STD-202C	Military Standard, Test Methods for Electronic and Electrical Component Parts
MIL-STD-810B	Environmental Test Methods for Aerospace and General Equipment

ATSM

B162-61	Sheet and Strip, Nickel Plate, Specifications for

HANDBOOKS

Aero Propulsion Lab, Wright Patterson AFB, Ohio

Screening Method, Edited by: J. E. Cooper and A. Fleischer	Characteristics of Separators for Alkaline Silver Oxide-Zinc Secondary Batteries

PUBLICATIONS

NHB 5300.4 (1B)	Quality Program for Space Systems Contractors, (Chapter 8: Nonconforming Article and Material Control)
NPC 200-3	Inspection System Provisions for Suppliers of Space Materials, Parts, Components, and Services

(Copies of documents required by suppliers in connection with specific procurement functions should be obtained from the procuring agency or as directed by the contracting officer.)

2.1 The following documents, of issue in effect on date of invitation to bid, constitute a part of this specification to the extent specified herein:

SPECIFICATION ST-A20403	SMS General Quantitative Reliability Assessment Specification
DRAWING 211530	Nickel-Cadmium Battery Cell Source Control Drawing

3. REQUIREMENTS

3.1 Design and Construction.-

3.1.1 General.- The storage cell(s) shall consist of the following parts.

a. Separators
b. Metal Container
c. Electrodes
d. Electrolyte
e. Insulation

Individual cells shall be hermetically sealed to permit operation within the environmental requirements of this specification. Cells shall contain the necessary plates and terminal posts and shall be secured so that no motion of the plates, relative to the container or hold-down arrangement, can occur. The detailed mechanical and electrical design of the nickel-cadmium storage cells shall be accomplished by the subcontractor subject to the requirements of this specification. Cell component test sampling shall be in accordance with MIL-STD-105 or as specified herein.

3.1.2 Separators.- Separators shall be of an approved type for satellite application, free from flaws, cracks, or other imperfections likely to permit short circuits. They shall be fabricated from materials which are physically and chemically stable in the presence of potassium hydroxide. (Materials shall be selected in accordance with the requirements specified herein.) They shall have a low electrical resistance and shall be capable of absorbing and retaining large quantities of potassium hydroxide electrolyte when subjected to the environmental conditions. Separators shall also be capable of withstanding the thermal tests without damage. (See 4.4.3 and 4.4.4 which are representative of environmental conditions anticipated during the seven years of minimum battery life.) The separator style and type shall be subject to Philco-Ford approval.

3.1.2.1 Separator Tests.- The following tests shall be conducted on the separator to be used for cells purchased under this specification. Processing and test requirements are included in Appendix A. Two copies of each data sheet and a separator sample of 100 square inch minimum size shall be furnished to Philco-Ford prior to start of further processing. Material traceability shall be required.

a. Electrolyte Absorption
b. Electrolyte Retention

3.1.2.1 Separator Tests.-(Continued)

c. Porosity

d. Extractable Organic Content

e. Inorganic Content

f. Discoloration of Separator in Electrolyte

g. Tensile Strength at Break

h. Thickness Variation

i. Resistance

j. Wettability

3.1.2.2 Separator Configuration.- The separator material-cell plate configuration shall be designed to preclude any electrical short circuits caused by misalignment of cell components. The vendor shall submit the candidate separator configuration designs to Philco-Ford for verification.

3.1.3 Electrodes.- The electrode materials shall be identifcal to those used in cell qualification as stated herein. No changes in material quality, contents and manufacturing technique shall occur without written approval by Philco-Ford.

3.1.3.1 Specifications.- Two copies of either the electrode purchasing specifications or the manufacturing process specifications delineating the process from raw materials through impregnation and storage for use on cells as specified herein shall be furnished to Philco-Ford prior to start of further processing.

3.1.3.2 Certification.- Two copies of the electrode suppliers certification for both positive and negative electrodes used herein shall be furnished to Philco-Ford prior to start of further processing. The certification shall contain the following minimum information:

a. Assigned plate batch number

b. Spiral number or lot number

c. Date of impregnation

d. Percent porosity

e. Weight of active material per plate

3.1.3.2 Certification.- (Continued)

f. Negative capacity obtained

g. Positive capacity obtained.

NOTE: Sample results, based on a reasonable sample from each positive and negative spiral, are acceptable for items d through g above and tolerances are to be supplied by subcontractor.

3.1.4 Electrode Assembly.- Production processing and test operations on cell electrode assemblies consisting of initial inspection of plates, through formation, addition of KOH and sealing of cell with gauge assembly shall be controlled in accordance with Appendix B.

Manufacturing and inspection operations on completed positive and negative plates shall be controlled as follows prior to their formation:

a. Inspection of coining and other operations affecting the integrity of the sinter and grid.

b. Edges shall be coined to prevent flaking of sinter material.

c. Visual inspection of plates. (100 percent inspection on positive and negative plates prior to assembly into formation pack.)

NOTE: Inspection criteria shall be established by the Subcontractor reflecting items listed in paragraph d.1 through 9. Sample plates showing each type defect shall be posted at inspection station. Dimensional checks of the plates shall be in accordance with the applicable drawings.

d. Plates shall be rejected if defects as listed below are found. (See Note 6.4):

1. Crack detected in sinter sufficient to cause loose or missing active material. Plates suspected of loose active material shall be inspected by 10X.

2. Rough edges, burrs and snags exceeding 0.001 inch. (inspection will be made with nylon gloves to feel for pulls on fibers of gloves. Inspection will include the entire electrode surface.)

3. Examine surfaces for evidence of sinter materials breaking away from grid.

3.1.4 Electrode Assembly.- (continued)

4. Electrodes shall be of uniform thickness over entire surface area to within ± .001 inch. A 10 percent random sample shall be selected for thickness determination. If all samples can meet this thickness requirement, then all plates are acceptable. If one or more plates from this sample is not acceptable, then all electrodes of the manufacturing lots shall be inspected. Electrodes which cannot meet this requirement shall be rejected. Electrode thickness shall be measured by an Ames gage or equivalent.

5. Tab shall be free of sinter material.

6. Edges which are coined shall be uniform, (i.e., within ± 0.015 inch, visual verification only).

7. Grid support for sinter material shall be free of any breaks or cracks.

8. Plate Weight Screening - Establish the average weight of the positive electrode and negative electrode by a screening method. Then each plate shall be screened by a GO-NO GO technique. Each plate weight shall be within 3.5 percent of the average established plate weight. The subcontractor shall establish detail procedures and submit to Philco-Ford for approval prior to start of task. The subcontractor shall establish an acceptance procedure and furnish information to Philco-Ford.

9. Plate Samples - The subcontractor shall supply Philco-Ford with 20 unformed acceptable positive electrodes and 20 unformed acceptable negative electrodes from the plate lot used in the production of this cell lot. Each electrode type shall be placed in a polyethlyene bag, heat sealed, and permanently marked with the plate lot number.

3.1.4.1 Electrode Capacity.- The electrode capacity test shall provide a measure of the discharge capacity of the positive (nickel) electrode and of the negative (cadmium) electrode of nickel-cadmium cells as separate data under a standard set of conditions. This test shall be run in a manner such that the excess negative capacity beyond complete discharge of the positive electrode (or excess positive capacity beyond the negative electrode in case of cell that may be negative limited on discharge) may be determined in addition to the total capacities of the electrodes. These data may be used to establish one or more of the following:

a. Range and distribution of positive capacities.

b. Range and distribution of negative capacities.

c. Difference between and/or ratio of total negative and positive capacities.

d. Excess negative on discharge.

e. Excess negative on charge.

The required total positive and negative electrode capacity characteristics are specified in Table I. Any non-compliant capacity level obtained under the conditions defined in Appendix B is subject to immediate notification to Philco-Ford for verification.

Table I

Summary of Electrode Capacity Characteristics

Capacity Ratio (Ampere-hour)	Maximum	Minimum
Actual Positive/Rated Positive	1.50:1	1.20:1
Total Negative/Positive	1.80:1	1.50:1
Excess Negative/Negative Precharge*	2.85:1	2.25:1

*Negative precharge - the ampere hour capacity introduced into the negative electrodes of a full discharged cell.

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3.1.5 Metal Container.-

3.1.5.1 General.- The cell case shall be drawn. The case material shall be type 304L stainless steel in accordance with QQ-S-766 , and shall be 0.018 ± 0.006 inch in thickness.
Electric arc welding using inert gas shielding per MIL-W-8611 shall be used for container component junction welding. All welded areas shall be passivated in accordance with MIL-F-14072, Finish E-300, or an equivalent process approved by Philco-Ford.

3.1.5.2 Cover.- The cell cover shall be made from class 304L stainless steel in accordance with QQ-S-766, Condition A.

Metal parts shall be inspected for conformance to drawings, physical dimensions, surface defects, and burrs that may interfere with intended function.

3.1.5.3 Cover-to-Case Junction.- The cover shall be electric-arc welded to the case using inert gas shielding. No welds beyond dimensional limits shall be permitted. Weld joints shall not be ground or polished. Weld beads shall be smooth and free of folds. Repair welds are acceptable provided repair areas meet the above weld requirements and the repair is accomplished by using filler wire conforming to specification MIL-R-5031 Class I or II.

3.1.5.4 Metal Container Quality Assurance Provisions.- The subcontractor shall supply with every order, the supplier, name, alloy designation, batch number, and chemical composition of raw material with certified analysis. Two copies of this information shall be furnished to Philco-Ford. The tolerances on the cell case wall thickness shall be within ± 0.0025 inches. The completed cell shall conform to Philco-Ford approved drawings. Each can shall be visually examined for blemishes, pits, cuts, cracks, burrs, file marks, weak points, incomplete penetration or any other visual defects. Only high quality cell cases shall be accepted.

3.1.5.5 Container Finish.- The cell case and cover shall be made of an alkaline resistant material or thoroughly covered with an alkaline resistant material. It shall be capable of withstanding 1.33 specific gravity potassium hydroxide (KOH) for at least 168 hours at any temperature from minus 37°C to plus 82°C without penetration of electrolyte, whitening, checking, blistering, or showing any trace of corrosion or appreciable change in hardness. This finish shall also withstand a test for flexibility after heat treatment of 93°C. The interior of the cell container shall be constructed and the applicable parts lined with an alkaline resistant material so that it will be capable of withstanding 1.33 specific gravity KOH for a period of 150 hours at 93°C without physical change in the lining material such as blistering, sagging, checking, or breakdown in dielectric strength.

3.1.6 Terminals.- Terminals provided for positive and negative electrodes shall be rated at not less than 6.0 amperes continuous duty. The terminals shall be made from 304 stainless steel, in accordance with QQ-S-766, Condition A, or nickel 200 in accordance with B162-61. The positive and negative terminals shall be insulated from the cell cover by means of ceramic insulators having an alumina content of 96.00 ± 1.00 percent. The insulator-to-cover junction shall employ a stress-relief configuration such that relative motion between the terminal assembly and the cover applies minimum stress to the insulator and to the metal-to-insulator bonds. The collar-to-insulator and insulator-to-terminal bonds shall be made using a metal-to-ceramic bonding process subject to approval by Philco-Ford. Any silver containing braze materials used for metal-to-ceramic bonding or elsewhere in the cell shall be nickel plated to a minimum thickness of 0.00015 inches. A dull-matte nickel plating process shall be used and the process specification shall be subject to approval by Philco-Ford. The cell terminals shall be constructed as shown in Figure 1. The terminals shall be fitted with a 4-hole solder lug. The lugs shall be tinned as per Appendix C, 40. The solder lugs shall be brazed to the cell terminal.

3.1.6.1 Control and Testing of Feedthrough Terminals and Seals.- Materials, manufacturing and test operations on the cell feedthrough terminals, seals and related hardware shall be in accordance with Appendix C. Two copies of all data obtained herein shall be furnished to Philco-Ford prior to further processing.

THE SUBCONTRACTOR SHALL PROVIDE THE TERMINAL CROSS SECTIONAL VIEW

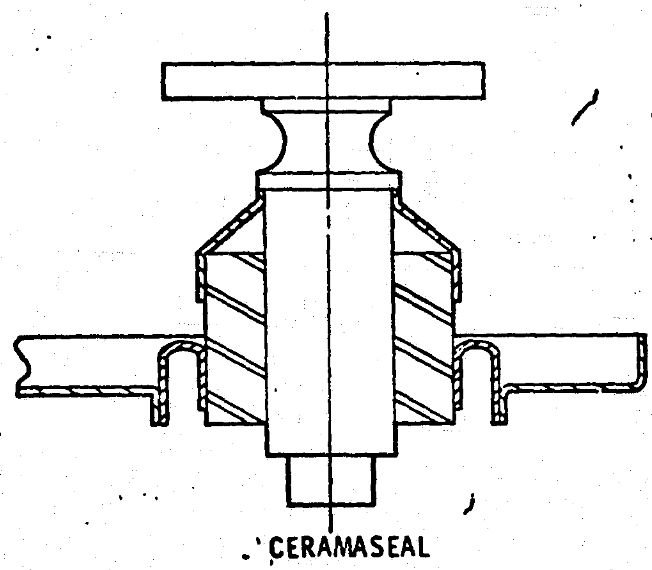

FIGURE 1 CERAMIC-TO-METAL SEAL TERMINAL CROSS-SECTIONAL VIEW

3.1.7 Size and Weight.- The size and weight of the storage cell shall not exceed the limitations specified in Specifications Control Drawing DS-2`1530. The total weight of all deliverable cells divided by the total number of deliverable cells shall not exceed 162. grams.

3.1.8 Gas Tightness of Cells.- The hermetically sealed cell shall be designed to withstand an internal gas pressure of at least 225 psia at 58°C without leakage for 30 minutes at any ambient pressure from one atmosphere minimum to a vacuum of 9×10^{-14} Torr or greater. In order to permit satisfactory leak detection procedures to be used on sealed equipment, all cells shall contain between 5 and 10 percent of helium gas by volume, at the time of sealing. The design objective for each item shall be zero leakage at the expected pressure differential. The maximum allowable leak-rate of the sealed cell shall be 10^{-8} standard cc of helium per second.

3.1.9 Electrolyte Activation.- All cells shall be stored in a dry inert gas environment prior to activation with KOH electrolyte (Appendix C). Cells from one manufacturing lot shall be activated in accordance with an activation schedule to be specified by Philco-Ford. Activated cell wet life shall be minimized.

3.1.10 Interchangeability and Replacement.- All parts having the same manufacturer's part number shall be functionally and dimensionally interchangeable. The provisions of MIL-STD-454, Requirement 7, shall apply.

3.1.11 Cell Lot.- Cells to be purchased under one lot shall use components from one specific batch only and shall be assembled as one batch under identical production techniques. This requirement must be strictly adhered to. Complete records must be kept of each component batch and be made available to Philco-Ford upon request. Each cell shall be serialized with a non-recurring number.

3.1.12 Parts, Materials and Processes.- Selection criteria for parts, materials, and processes shall be as required by this specification and the Statement of Work.

3.1.12.1 Identification and Marking.- Each piece of equipment furnished under this specification shall have a nameplate for identification in accordance with MIL-STD-130 and as specified herein.

3.1.12.2 Manufacturing Data.- The manufacturer shall maintain a log on the history of each cell by recording the following data:

a. Serial number of cell

b. Date of manufacture (date of pinch-off)

c. Date of activation (addition of electrolyte)

d. Type and duration of electrical tests performed on cells.

3.1.12.2 Manufacturing Data.- Continued)

e. Charge and discharge method and rate used in electrical tests.

f. End of charge and discharge voltages

g. Test conditions

h. Test results including failures

i. Material traceability (This consists of complete records of cell components including batch numbers and components. This item to be maintained at vendor.)

This lot shall be maintained on all cells manufactured under this specification and shall be available to Philco-Ford on request.

3.1.12.3 Identification of Product.- The manufacturer shall identify each cell by electro etching serial number plus date of activation on the cover area. In addition, cells that are delivered to Philco-Ford shall be imprinted or tagged as follows:

Weight ____________ A.H. at 2 Hour Rate ____________

Date of Activation ____________ Type Nickel - Cadmium ____________

Manufacturer Model No. ____________

Manufacturer Serial No. ____________

Philco-Ford Part No. 211530

____

3.1.12.4 Polarity Markings.- The polarity of the positive terminal shall be plainly indicated on the container cover by electro etch or by other Philco-Ford approved methods.

3.1.13 Workmanship.- Standards of workmanship shall meet or exceed MIL-STD-454, Requirement 9. The subcontractor shall submit his workmanship standards for Philco-Ford approval. Material delivered shall comply with these approved standards.

3.1.13.1 Neatness.- To include thoroughness of soldering, wiring, conformal coating, marking of parts, and assemblies, plating, welding, brazing and freedom of parts from burrs and sharp edges.

3.1.13.2 Cleanliness.- Precautions shall be taken to prevent contamination of the equipment during manufacturing, handling, and shipping. The seller shall maintain adequate controls to assure consistence in maintaining acceptable workmanship and cleanliness levels.

3.1.13.2 Cleanliness.- (Continued)

Quality workmanship and cleanliness standards, including any required visual aids, shall be established and submitted to Philco-Ford for approval.

3.2 Cell Performance.-

3.2.1 Capacity.- The cell shall meet the following capacity tests:

Condition	Temp. (°C)	Discharge Current (Amps)	Discharge Time	Min. Voltage (Volts)	Min. Required % Rated CAP. (100% = 3.AH)
1	24 ± 2	1.5	2.4 Hrs	1.00	120%
2	0 ± 2	1.5	2.0 Hrs	1.00	100%
3	40 ± 2	1.5	1.3 Hrs	1.00	65%

3.2.1.1 Capacity After Cycling.- The cell discharge capacity shall be a minimum of 2.4 ampere-hours after 700 charge-discharge cycles of 1.2 hour discharge at 1.5 amperes and 22.8 hours charge at 0.3 amperes. In addition, the discharge voltage shall be a minimum of 1.16 volts during the 700 discharge cycles. The temperature of the cell shall be cycled through an eclipse temperature profile during each charge - discharge cycle. The charge temperature for each cycle shall be 24°C for the first 400 cycles, 18°C for the next 300 cycles. The cell capacity retention shall be measured after every 50 cycles.

3.2.1.2 High Rate Discharge.- Each cell must be capable of being discharged at the 5C (15 amps) rate for a minimum of two minutes. The minimum allowable cell voltage is 1.0 volts.

3.2.2 Charging.- All cells shall be capable of being charged at a maximum charge rate of 0.3 amperes. Charging shall be accomplished within the maximum limiting voltage constraint specified in Figure 2. Each cell shall be capable of being charged from 50 percent to 100 percent state of charge at this 0.3 ampere rate without exceeding the limiting voltage value specified in Figure 2. (This charge shall include the overcharge necessary to account for the ampere-hour efficiency value of the cell at a particular temperature.) (See Figure 3.) All cells shall be capable of accepting continuous overcharge currents up to the maximum values shown in Figure 4 without exceeding 75 psig internal cell gas pressures and the limiting voltage value specified on the lower curve in Figure 2.

3.2.3 Retention of Charge.- Each cell shall be free of short circuiting paths between negative and positive terminals and shall maintain an open circuit voltage of no less than 1.16 volts when tested in accordance with 4.4.7. The cell discharge capacity in ampere-hours shall not be less than 70 percent of its initial capacity when discharged 30 days after being fully charged. The cell shall meet the provisions of this paragraph when charged and discharged at the rates and periods specified in Paragraph 3.2.1. During the 30 days stand time, the cell temperature shall be maintained at 26°C.

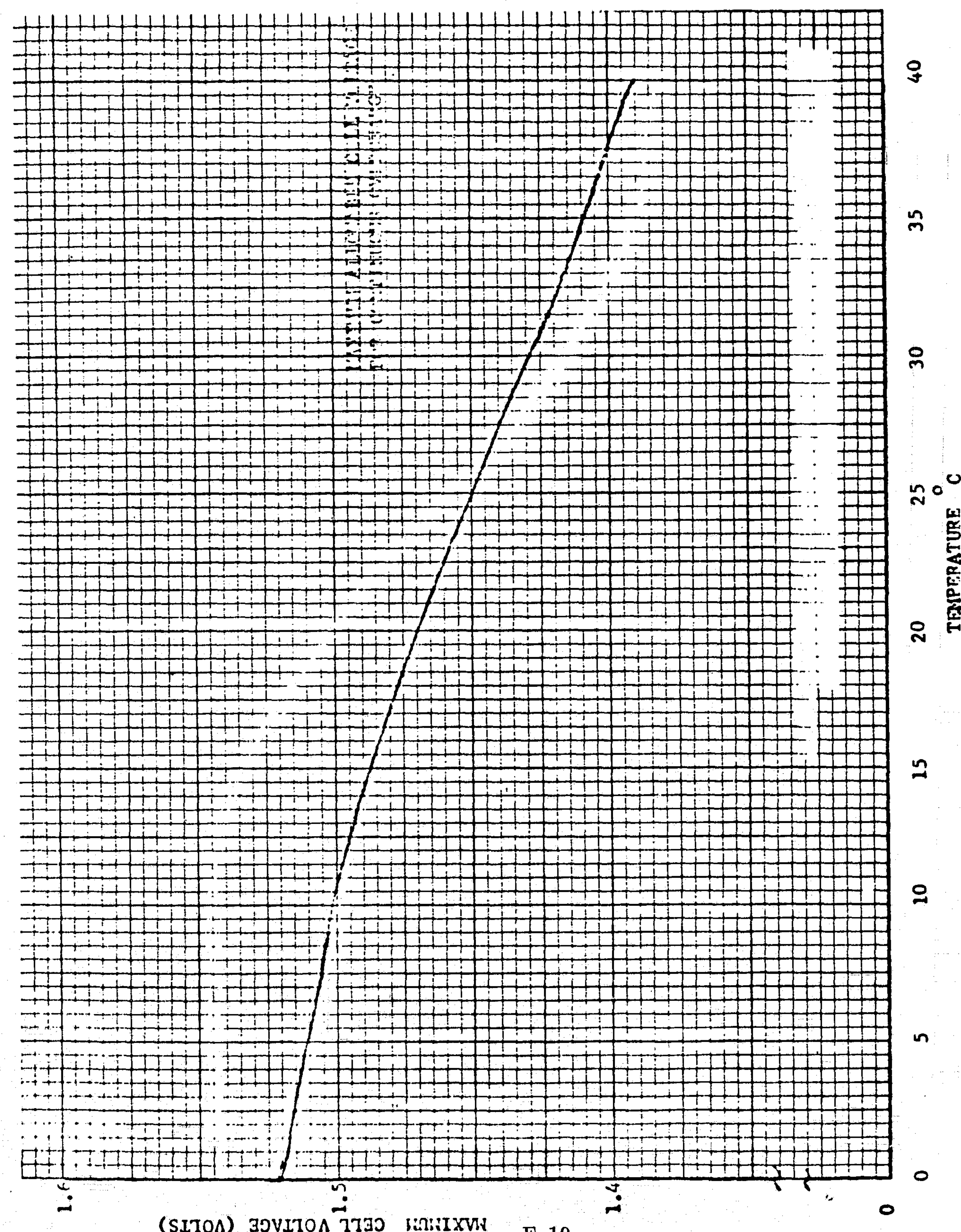

FIGURE 2 MAXIMUM LIMITING VOLTAGE FOR CHARGE CONTROL OF HERMETICALLY SEALED NICKEL CADMIUM CELLS

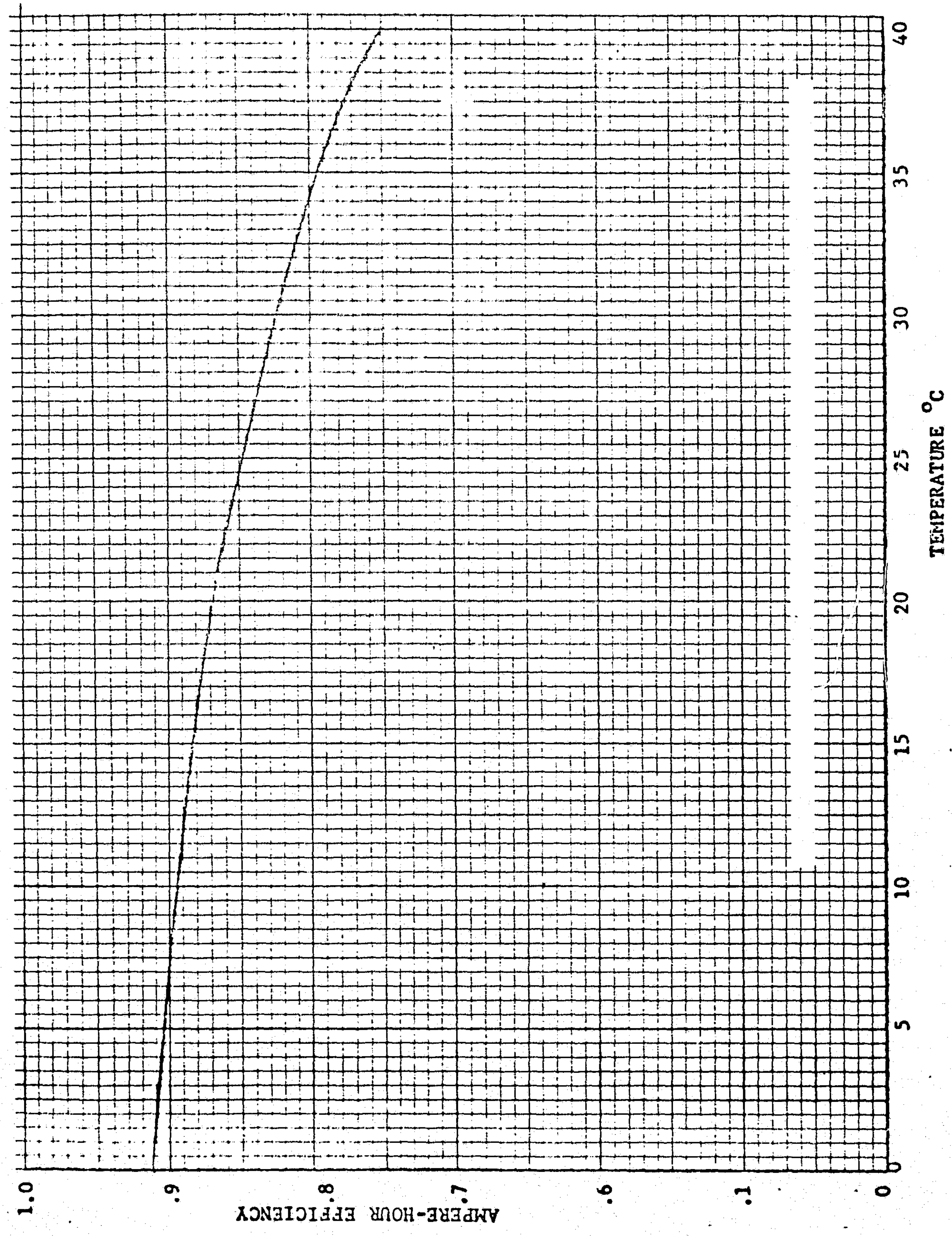

FIGURE 3 AMPERE-HOUR EFFICIENCY VERSUS TEMPERATURE

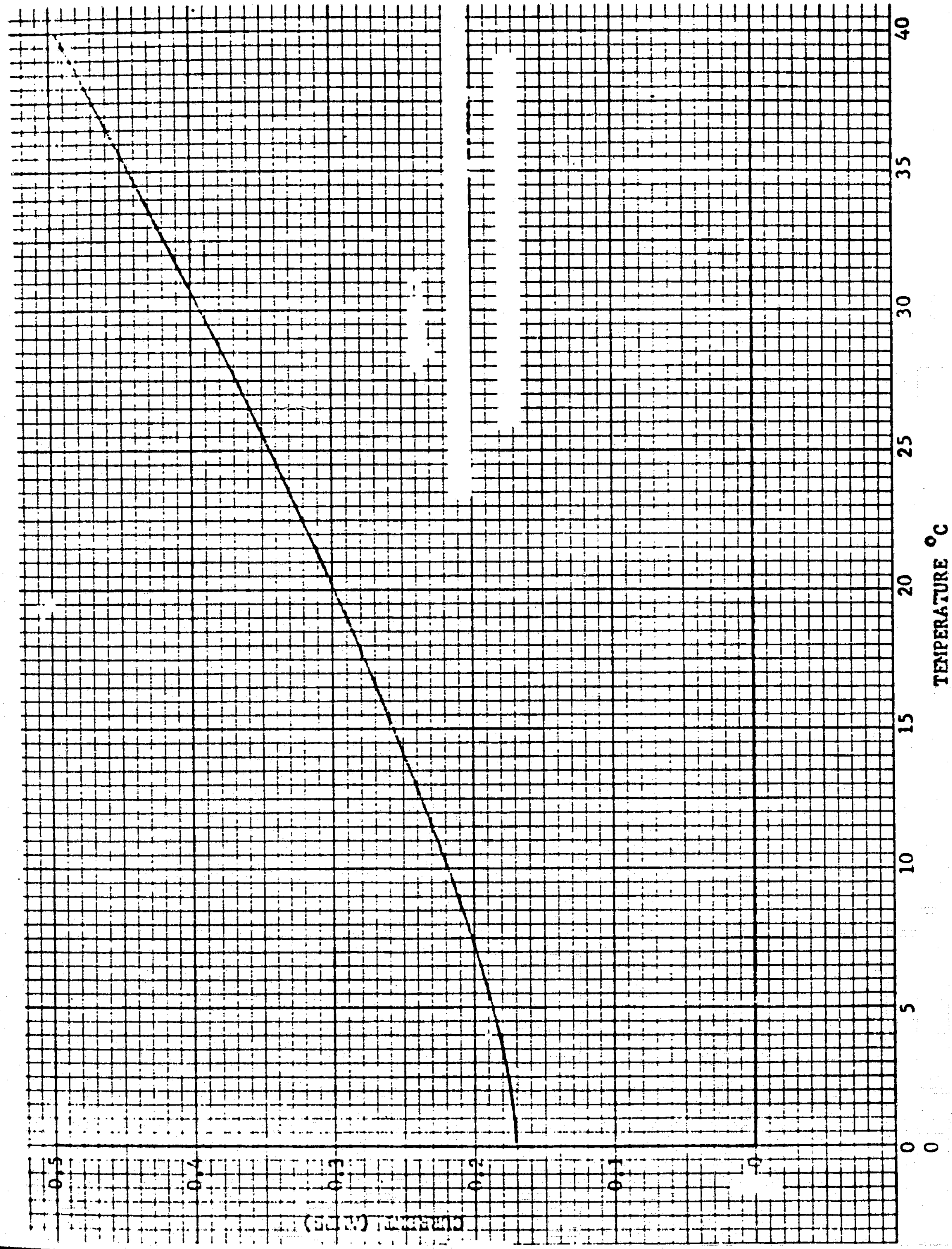

FIGURE 4. MAXIMUM SAFE CONTINUOUS OVERCHARGE CURRENT VS. TEMPERATURE

3.2.4 Internal Impedance.- Each cell shall have an internal impedance not greater than 0.010 ohm.

3.2.5 Thermal Requirements.- The thermal design of the cells shall be such that satisfactory operation of the cells is assured under all operating conditions (including overcharge) when the battery container heat sink surface temperature is $0^{\circ}C$ to $35^{\circ}C$. The cell qualification temperature extremes of $0^{\circ}C$ to $40^{\circ}C$ provide for satisfactory operation outside the anticipated orbital extremes of 3.3.5.

3.2.6 Electrolyte Leakage.- The cell shall show no evidence of electrolyte leakage.

3.2.7 Storage.

3.2.7.1 In Dry (Unfilled) Condition.- The fully assembled, dry (unfilled) cell, when stored for periods up to three (3) years, shall show no detrimental performance effects.

3.2.7.2 In Filled (Sealed) Condition.- The cell in filled (sealed) condition shall be designed to be capable of being stored in a discharged and shorted condition for up to 24 months from the date of manufacture at a temperature of $16^{\circ}C$ to $27^{\circ}C$. Storage shall be in accordance with Philco-Ford recommended procedure. After activation, the cell shall be capable of meeting all performance requirements stated herein and shall show no performance deviations. After storage the cell shall be capable of meeting all performance requirements stated herein and shall show no performance deviation.

3.2.8 Operating Position.- The cell shall operate normally in any position and under any gravity condition specified in 3.3.4.

3.3 Environmental Requirements.- The environments described in this section are indicative of the transportation, storage, pre-launch, launch, and orbital operation conditions. The equipment shall be designed to meet specified performance requirements during and after any probable combination of operation environments and/or subsequent to exposure to nonoperational environments as specified herein based upon equipment duty cycle. Safety factors for design purposes shall be introduced commensurate with the reliability objectives. Sinusoidal vibration and random vibration level design requirements are shown in Tables II and III, and Figure 5.

3.3.1 Shipping, Handling and Storage.- The equipment will be subject to the following environments in a non-operating condition and packaged for shipment condition, unless otherwise noted.

TABLE II

BATTERY CELL
SINUSOIDAL VIBRATION LEVELS
(OMNIDIRECTIONAL)

FREQUENCY (Hz)	LEVEL (g,0 to peak)
5 - 10	0.5" DA
10 - 20	14.0
20 - 23	7.0
23 - 30	12.5
30 - 60	25.0
60 - 80	8.0
80 - 200	3.0
200-2000	5.0
Note: Sweep rate is 2 octaves/minute for all spectra.	

TABLE III

BATTERY CELL RANDOM VIBRATION LEVELS

Axis	Frequency Range (Hz)	PSD Level (g^2/Hz)
xx,yy & zz	20-40	Roll-off below 40 Hz at rate of 6 db per octave
	40-300	0.18
	300-600	Roll-off a rate of 6 db per octave
	600-2000	0.045
Over-all acceleration is 10.9 grms. Duration per axis is four minutes.		

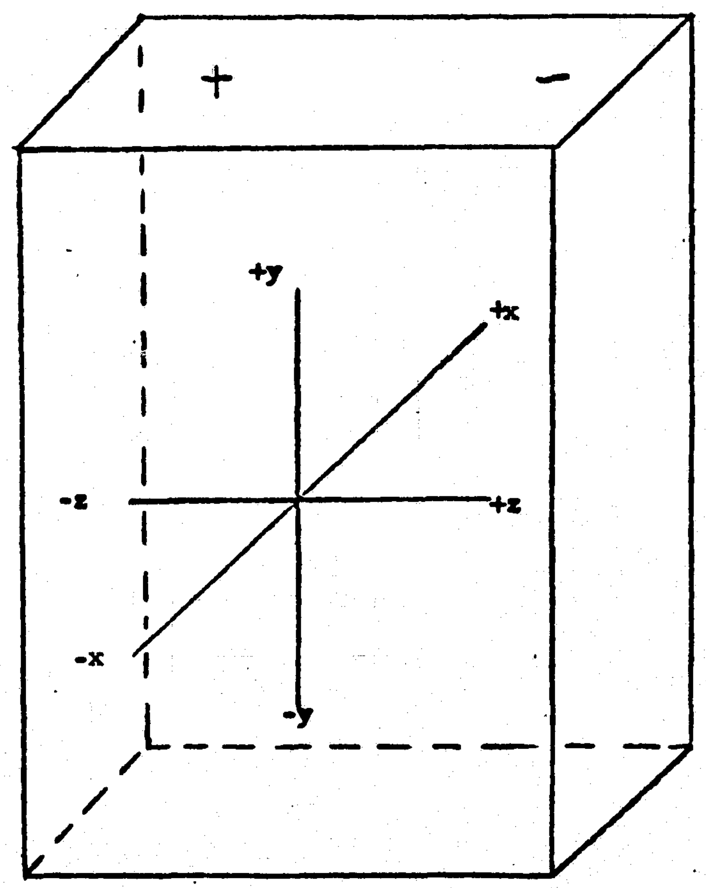

FIGURE 5 BATTERY CELL AXES FOR VIBRATION

3.3.1.1 Temperature.- Temperatures ranging from minus 30°C to plus 60°C will be encountered.

3.3.1.2 Altitude.- Pressures equal to an altitude of 50,000 feet will be experienced during air shipment.

3.3.1.3 Humidity.- Relative humidities of up to 100 percent will be encountered.

3.3.1.4 Shock.- Handling shocks, including flush drops of up to one (1) inch, and pivot drips of up to four (4) inches from all probable orientations, will occur with unpackaged equipment in its handling and/or mounting fixtures. Shocks in shipment by common carrier will be encountered as described in MIL-STD-810 , Method 516.1, Procedure I.

3.3.1.5 Vibration.- Vibration in shipment by common carrier will be encountered as described in MIL-STD-810, Method 514.

3.3.2 Temperature.- Non Flight.

3.3.2.1 Non-Operating.- Each cell shall be capable of meeting all the requirements of this specification after being subjected in a temperature of -30°C maintained for at least twelve hours followed by +40°C maintained for at least twelve hours.

3.3.2.2 Operating.- Each cell shall be capable of meeting the requirements of this specification at the temperatures of 0°C, 24°C, and 40°C without failure or electrolyte leakage.

3.3.3 Thermal Vacuum.- Each cell shall be capable of meeting the requirements of this specification (including the non-operating requirements of 3.3.2.1) in a vacuum of at least 1 X 10^{-14} Torr.

3.3.4 Acceleration Plus Sustained Loads.- Equipment will experience a longitudinal quasi-steady acceleration of 16.8 g ultimate at approximately first-stage burnout. A maximum sustained acceleration of 19.5 g ultimate in the longitudinal direction will be experienced during Apogee Boost Motor (ABM) burn. The maximum radial acceleration during spin-up at ABM burn and during orbital operation will bc 25.8 g ultimate at satellite periphery.

3.3.5 Synchronous Orbital Conditions.- Equipment operating.

3.3.5.1 Temperature.- The equipment shall operate and meet all requirements over tne temperature range of 0°C to plus 35° as measured at the equipment baseplate. The equipment shall survive without damage in the non-operating mode over the temperature range of -30°C to +40°C.

3.3.5.2 Radiation.- The equipment will be subjected to particle and solar radiation as described in Table IV modified by the satellite structure, shielding effects and the equipment geometrical location.

3.4 Reliability.- Reliability requirements are as defined in the following paragraphs.

3.4.1 Reliability Program Plan.- A Reliability Program Plan shall be developed and implemented as described in the Statement of Work. The data in the subparagraphs below represents the specified quantitative requirements to be used in the analytical efforts of the Program Plan.

3.4.2 Life Requirements.- The equipment shall have an operating life of not less than five years in orbit after successfully withstanding the environmental stresses of the mission pre-launch activities, launch, and insertion into a synchronous orbit.

3.4.3 Shelf Life Requirement.- The equipment shall have the capability of meeting all requirements specified herein after a shelf life of at least two (2) years in accordance with 3.2.7.2.

3.4.4 Success Probability Requirements.- The Reliability shall be assessed according to the methods of ST-A20403; the calculations shall be subject to detailed review and approval.

3.4.4.1 Pre-Launch and Launch Survival.- The equipment shall survive the specified pre-launch and launch environments and placement into orbit in readiness for operation (P_L) with a probabilty of not less than 0.9999.

3.4.4.2 Orbit Survival.- The equipment shall successfully perform its designed and specified function in the specified orbital environment for a period of five years with a probability of success (P_s) of not less than 0.9977, assessed over the mission as described in ST-A20403 and including the cycles of discharge associated with eclipse periods and charge maintenance in the balance of the mission.

TABLE IV

PARTICLE RADIATION LEVELS

PARTICLE	ENERGY (Mev)	FLUENCE (cm^{-2})
PROTONS	>0.1	6.4×10^{14}
	>0.2	2.8×10^{14}
	>0.4	7.4×10^{13}
	>0.8	2.1×10^{12}
	>1.0	2.3×10^{11}
	>4.0	1.3×10^{11}
	>10	3.3×10^{10}
	>30	6.2×10^{9}
	>100	8.0×10^{8}
	>500	2.4×10^{7}
ELECTRONS	>.01	1.1×10^{16}
	>.1	5.5×10^{15}
	>.5	7.6×10^{14}
	>1.0	7.0×10^{13}
	>2.0	7.0×10^{11}
	>5.0	5.7×10^{5}

4. QUALITY ASSURANCE PROVISIONS

4.1 General.- This section covers Quality Assurance requirements that shall be implemented during design and manufacturing phases to assure timely implementation of adequate controls in accordance with NHB 5300.4(1B) (Chapter 8) and the Philco-Ford approved Quality Assurance Plan to ensure that materials, workmanship and performance are to specified standards; and components have been manufactured and tested to approved drawings and specifications. All inspection procedures shall be in compliance with specification NPC 200-3.

4.2 Classification of Tests.- The inspection and testing of the nickel-cadmium storage cells and component parts shall be classified as follows:

	Type of Test	Quantity of Cells to be Tested
a.	Development Tests	As Required
b.	Acceptance Tests	Each Deliverable Cell

4.2.1 Development Tests.- Development tests are those tests conducted at the discretion of the subcontractor for the purpose of providing data to be used in the design of the nickel-cadmium storage cells.

4.2.2 Acceptance Tests.- Acceptance tests shall be conducted in the sequence shown on each production cell to demonstrate the continuance of quality of each unit. Tests shall include, but not necessarily be limited to, those shown on the Test Matrix.

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TABLE V

ACCEPTANCE

TEST MATRIX

PARA. REF.	ACCEPTANCE TEST	Capacity (3.2.1)	Capacity after cycling (3.2.1.1)	Retention of Charge (3.2.3)	Electrolyte Leakage (3.2.6)	Leak Detection (3.1.8)	Workmanship (3.1.13)	Construction (3.1.7)	Interchangeability (3.1.10)	Sealing (3.1.8)	Cell Container (3.1.5.5)	Weight (3.1.7)	Dimensions (3.1.7)	Identification Marking (3.1.12.1)	Packaging (3.3.1)	Terminals (3.1.6)	Electrodes (3.1.3)	Gas Tightness of Cells (3.1.8)	Capacity (3.2.1)
App.B 30.1	Cell Electrical																X	X	
30.2,30.3	Operations Requirements Supply Data																		X
4.4.1	Examination of Product						X	X	X	X	X	X	X	X	X	X			
4.4.5	Leak Detection					X													
4.4.6	Electrolyte Leakage Test				X														
4.4.7	Retention of Charge			X															
4.4.2	Capacity Test at 24°C	X																	
4.4.3	Capacity Test at 35°C	X																	
4.4.4	Capacity Test at 0°C	X																	
4.4.2	Capacity Test at 24°C		X																
4.4.6	Electrolyte Leakage				X														
4.4.7	Retention of Charge			X															
4.4.5	Leak Retention					X													

SRS-4284 (8-68)

4.3 Test Equipment Calibration.- All test equipment used to conduct tests specified herein shall be calibrated in accordance with MIL-C-45662.

4.3.1 Measurement Accuracy.- Total measurement uncertainty, including that due to limited accuracy of the test equipment used shall not exceed 10 percent of the tolerance specified for the parameter being measured. Exceptions to this requirement, if any, shall be submitted to Philco-Ford for approval.

4.4 Test Methods.-

4.4.1 Examination of Product.- Each complete cell, submitted for qualification and acceptance under this contract, shall be inspected to determine compliance with this specification and the applicable drawing, with respect to workmanship, construction, interchangeability, sealing, cell container, weight, dimensions, identification marking, packaging and packing, and terminals.

4.4.1.1 Inspection of Cell Assembly.- The final cell assembly shall be witnessed by a Philco-Ford quality assurance representative to verify the integrity of internal and external component parts.

4.4.1.2 Hermetic Seal.- The cell shall be tested for seal leakage (helium) in accordance with Standard MIL-STD-202 , Method 112 Test Condition C, Procedure IV, at a chamber pressure no greater than 10^{-5} Torr maintained until the leak rate stabilizes. The hermetic seal shall meet the requirements of 3.1.8.

4.4.1.3 Internal Impedance.- The cell impedance shall be measured between the positive and negative terminals at 60 Hz. The impedance shall be measured by passing a known AC current through the cell and measuring the AC voltage developed. The circuit shown in Figure 6 or its equivalent, shall be used. The impedance shall be measured when the cell is charged to a minimum of 10 percent of full charge.

4.4.1.4 Radiographic Examination.- Radiographs shall be taken of each unit for inspection for workmanship, foreign metallic particles and drawing compliance. Two radiographic views shall be provided for each unit Prior to welding the cover to case, a view of each narrowside along the Y axis shall be provided no more than four cells shall be included in each radiograph taken of the edge view. As a minimum each radiograph shall contain, cell serial number, positive or negative terminal location, view number, suitable control number, date radiograph was taken and an image quality indicator. All radiographs shall have good clarity. Prior to the performance of this task, the subcontractor shall submit to Philco-Ford for review and approval a Radiographic Examination Procedure. Radiographs of all units purchased herein shall be submitted to Philco-Ford prior to shipment of the units.

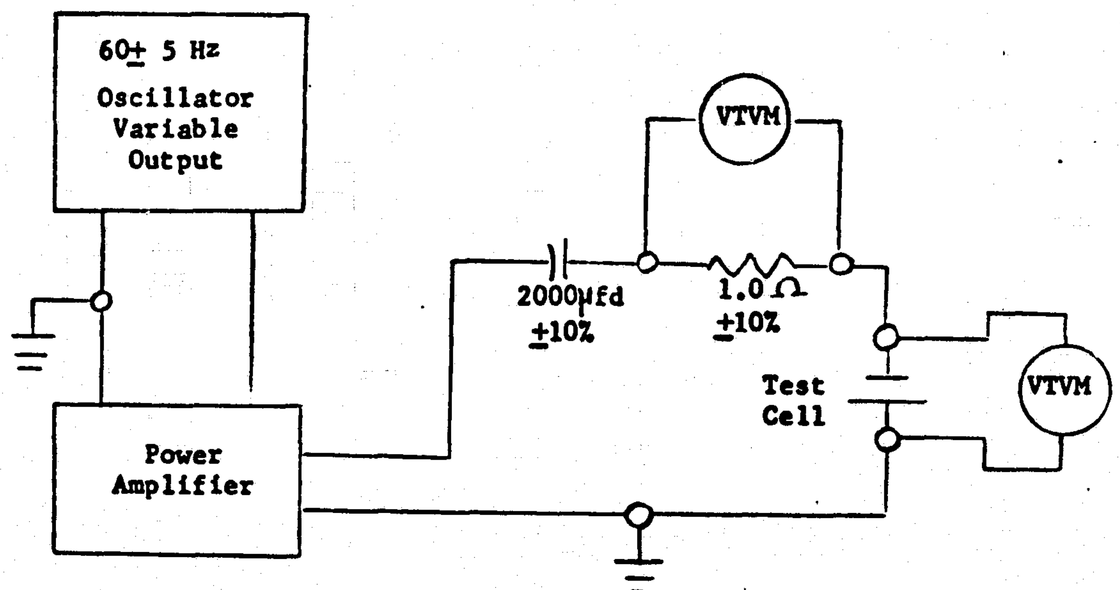

FIGURE 6 INTERNAL IMPEDANCE CIRCUIT

4.4.2 Capacity.- Unless otherwise specified, the capacity test shall be performed at $24^{\circ} \pm 2^{\circ}C$ ambient temperature. Ampere hour capacity shall be measured to the cutoff voltage given for the rate specified and shall not be less than the capability specified in 3.2.1. Each cell shall be discharged to 1.0 volt and placed on a 1.0 ohm resistive load for 16.0 hours, then short circuited for a minimum of one hour. The cell shall be charged at C/10 (0.30 ampere) for 20$\pm$.5 hours then placed on an 1.0 hour open circuit stand. The discharge capacity shall be greater than 3.6 ampere hours at C/2 (1.5 amperes) rate to the specified cutoff voltage. At no time shall the voltage on charge exceed the specificed maximum cell voltage shown in Figure 1, and at no time shall the discharge voltage fall below 1.0 volts.

Notes:

1. The voltage on charge shall never exceed the specified maximum cell voltage shown in Figure 2.

2. Each cell voltage, cell pressure and external cell case temperature shall be recorded as follows:

   a. Immediately prior and after start of each charge or discharge step

   b. At one hour maximum intervals during all charges

   c. At 15 minute maximum intervals during all discharges.

4.4.3 High Temperature Capacity.- With the cell temperature maintained at $35 \pm 2^{\circ}C$ during charging and discharging, the discharge capacity shall not be less than 2.0 ampere hours when charged at C/10 (0.3 ampere) for 20 $\pm$ .5 hours placed on open circuit for one hour and discharged at the two hour rate (1.5 amperes) to the cutoff voltage specified in 3.2.1. Before charging each cell shall be fully discharged with a 1.0 ohm resistor placed across the terminals for 16.0 hours then shorted for 1.0 hour, and stabilized at the test temperature for 6.0 hours. The maximum charging voltage shall not exceed the level specified in Figure 2.

4.4.4 Low Temperature Capacity.- The cell temperature shall be maintained at $0 \pm 2^{\circ}C$ for 6.0 hours prior to and during charge and discharge. Each cell shall be fully discharged with an 1 ohm load for 16 hours and shorted for a minimum of 1.0 hour then stabilized at the test temperature. The charge voltage shall not exceed 1.52 volts during the 48 hours charge at 0.15 ampere rate. The deliverable capacity shall be 3.0 ampere hours at the C/2 rate (1.5 amperes).

4.4.5 Leak Detection.- To permit satisfactory leakage detection, all cells shall be sealed with 5 to 10 percent of helium gas by volume. A fully charged cell shall be allowed to cool to $24 \pm 2^{\circ}C$, at which time a leakage test shall be made. Cells shall have a leakage rate of less than the limits specified in 3.1.8.

4.4.6 Electrolyte Leakage.- This test shall occur immediately after completion of charge, during which cell must have received a minimum of 4 hours of overcharge to assure a positive cell pressure with respect to atmospheric pressure.

4.4.6 (Cont'd)

Prior to start of charge, the cell shall be thoroughly cleaned with distilled water and alcohol. All mechanically sealed areas on the cell cover shall be swabbed with phenolphthalein solution*. A red indication on the swab is evidence of electrolyte leakage. In the event of a positive indication, the cell shall be again cleaned and the test repeated. If a positive indication of leakage is present during the second leakage test, the cell shall be rejected. The supplier shall specify the cell restrainer design including restrainer screw torque.

4.4.7 Retention of Charge.- This test shall occur if the cell was discharged to 1.00 volt. Drain cell for 16 + 1.0,-0 hours at 24 ± 2°C ambient temperature using a one (1) ohm resistor. Let the cell stand at open circuit for 24 ± 0.5 hours at 24 ± 2°C ambient temperature. The cell voltage at the end of this open-circuit stand shall be 1.16 volts or higher.

4.4.8 Rejection Criteria.- Permanent rejection is applicable if the following has occurred:

a. Unit was exposed to temperatures outside the -40°C to + 50°C range regardless of time duration of over-temperature exposure.

b. Unit had received currents in excess of 18. amperes (6 C rate).

c. Unit had exhibited voltages 0.01 volts above the curve in Figure 2.

d. Unit was over discharged below 0.0 volts after activation.

e. Unit was physically damaged in any manner, such as from being dropped from a height greater than 1.0inch.

f. Unit failure of any electrical test.

4.4.9 Data Approval.- Two copies of all data obtained on tests described in 4.4 shall be furnished to Philco-Ford for approval prior to further processing.

4.5 Test Failure.-

4.5.1 Failure Definition.- A failure shall include. but not be limited to, an occurrence of any of the following:

a. Equipment performance which is functionally beyond the limits of design or test specifications or test procedures. (This applies to all engineering, production in-process test, pre-acceptance test, and acceptance test items.)

b. Equipment performance which is intermittent or erratic.

* 0.5 percent phenolphthalein in 50 percent alcohol and 50 percent distilled water solution. All areas where phenolphthalein was applied shall subsequently be rinsed with distilled water; then all areas shall be rinsed with acetone and the cell shall be placed in a vacuum chamber for one hour at a pressure of 1 Torr.

4.5.1 Failure Definition (Cont'd)

c. Piece, part, module, or component removal or replacement in hardware to restore acceptable functional performance of the next higher assembly.

d. Necessity of repeated adjustment to sustain acceptable equipment operation (initial or setup adjustments expected).

e. Equipment operation which has unexplainably drifted from initial or setup performance conditions. (This applies even though equipment performance may still be within specification limits).

f. Overstress of end-item hardware caused by test equipment when an evaluation of the change has not or cannot be ascertained.

4.5.2 Failure Procedure.- If failure occurs during the performance of a test, the procedure described below shall be followed:

a. The test shall be suspended, the cognizant Engineering Representative shall note the failure on the test data sheets, and the cognizant Philco-Ford quality assurance representative shall be notified immediately. The above-mentioned representatives shall jointly determine whether to continue the test, or route the unit under test to rework, or to the Material Review Board (MRB). In the event they are unable to reach an agreement, the unit will be routed to MRB.

b. If the unit under test is routed to rework it shall be returned to operating condition in conformance with the applicable drawings and specifications and, after inspection of the rework, resubmitted to test. The test sequence during which the failure occurred shall be repeated unless otherwise authorized by the cognizant Philco-Ford quality assurance and engineering representatives.

c. If a failure is due to a component part, it shall be replaced with an approved replacement.

d. If failure is due to marginal adjustment, the equipment shall be realigned or adjusted as required. If repeated readjustment is required, the equipment shall be replaced.

e. If the unit is routed to MRB, MRB shall decide whether to accept or reject the failed unit, and shall determine the extent of subsequent retesting.

f. A Failure Report shall be written and processed for each failure or out-of-specification performance subsequent to initial application of electrical power to the unit.

4.5.2 Failure Procedure (Cont'd)

g. When test equipment fails during performance of the test, the measurements in progress as the time failure was detected shall be repeated unless otherwise authorized by the cognizant Philco-Ford quality assurance and engineering representatives.

4.6 Test Reports.- Following completion of formal tests, test reports shall be prepared as defined in the Statement of Work.

5. PREPARATION FOR DELIVERY

5.1 Preservation, Packaging and Packing.- After completion of tests each unit shall be preserved within one week by performing the following:

a. Discharge each cell below 0.1 volt by clipping a one ohm resistor across the cell terminals.

b. Remove the one ohm resistor and short the cell terminals by wrapping a copper wire around cell terminals.

c. Place each cell in a polyethylene bag and an inert drying agent shall be added to exclude moisture. The bag shall be heat sealed.

Note: Cell serial number shall be clearly visible from the outside of the bag.

d. Package unit in a manner to avoid damage during shipment.

e. If the battery cell is to be kept in storage for periods in excess of one week, the battery cell shall be stored in a clean and dry area at 16^{o} to $26^{o}C$.

5.2 Marking for Shipment and Storage.- All marking on shipping containers shall be clearly legible from a distance of 36 inches and may be applied by stencil, number stamp or lacquer over coated gummed labels.

The equipment furnished hereunder is for space flight use. All marking shall be blue in color and in addition, all shipping containers and shipping documents for shall be marked as follows:

"ITEMS FOR SPACE FLIGHT USE"

6. NOTES

6.1 Intended Use.- The cells covered by this specification are intended for continuous duty in electrical systems of satellites. They will be used in combination with a solar cell array to provide energy storage and furnish peak power demands.

6.2 Definitions.

6.2.1 Cell Capacity.- Cell capacity is the discharge measured quantitatively in ampere hours at the specified discharge rate to the specified cutoff voltage.

6.2.2 Cutoff Voltage.- The cutoff voltage of a cell is defined as that discharge voltage which represents the complete discharge condition of the cell for a particular rate. Discharge beyond this voltage would yield an insignificant amount of useful energy.

6.2.3 Constant Current Discharge.- The discharge made at the rate specified until the final voltage reaches the specified cutoff value.

6.3 Charging Instructions.- The subcontractor shall furnish, with cells, one reproducible printed copy of charging instructions.

6.4 Alternate Procedure.- The subcontractor may submit an alternate procedure for any specified procedure of specification subject to Philco-Ford approval. Two copies of the approved documentation for use shall be furnished to Philco-Ford prior to application.

APPENDIX A

10. SCOPE

This appendix details the requirements for processing and testing the separators used in fabrication of a storage cell.

Two copies of the completed data sheets, and a 100 square-inch (minimum) piece of separator material shall be forwarded to Philco-Ford prior to start of further processing.

20. SEPARATOR TESTS

20.1 Electrolyte Absorption, Dimensional Changes, Electrolyte Retention and Porosity.- Six samples of each material shall be cut (in the machine direction) to 6.50 cm by 2.50 cm and individually measured using a standard die. The thickness of each sample shall be measured using an Ames gauge model 262 platform dial micrometer with a 0.5 inch diameter stainless steel anvil. Record on data sheets provided (see 20.1.1). The dial shall be graduated in 0.001 mm. An equivalent thickness measurement system is acceptable. Each sample shall be weighed to the nearest milligram on an analytical balance (record on data sheet 20.1.2) and then immersed in approximately 100 cc of aqueous potassium hydroxide (KOH) solution in non-corrosive containers with air tight covers. The concentration of the KOH solution shall be the same percent as used in the cell filling and shall be of the same quality. Dimensional changes shall be measured after three hours of equilibration. The samples shall be returned to their individual containers for an additional hour. At the end of one hour, the equilibrated samples shall be wiped across a clean lucite plate until no droplets are left on the plate. The sample shall then be re-weighed. (See Note 6.4).

a. Electrolyte Absorption: Electrolyte absorption is the difference between the wet equilibrated samples and the dry sample weights. Record data on dimensions, dimensional changes, and absorption on the 20.1.3 portion of the data sheets. (See Note 6.4).

b. Electrolyte Retention: Electrolyte retention shall be measured on the same samples after draining for 15 $\pm$ 5 minutes on a clean lucite plate positioned at a 45 $\pm$ 2 degree angle. The samples shall be re-weighed. During draining, the samples shall be enclosed in an inert atmosphere. Record data on 20.1.4 portion of data sheets.

c. Porosity: Porosity shall be calculated in a manner similar to that delineated under 20.1.5 on the data sheets. (See Note 6.4).

20.2 Tensile Strength at Break.- Tensile strength at break shall be measured on at least six samples, each two samples cut from a different roll. Separator tensile strength measurements shall be made on die cut speciments 12.7 cm by 2.5 cm, cut in the roll direction, each of which must be carefully examined for flaws. Samples containing cracks, nicks, or inclusions must be discarded. As least five samples of each material shall be run and the mean value reported. The tensile strength at break shall be measured on samples as received. For the tensile measurement, the load in pounds shall be measured at the breaking point. Samples breaking outside the area between the jaws are not included. The tensile strength test shall be repeated for 6 samples after being subject to 34% KOH solution at 70°C for 24 hours, then washed with H_2O and dryed.

The temperature and humidity test site shall be recorded on data sheet:

The temperature and humidity test site shall be recorded on data sheet:

Calculations:

$$\text{Tensile strength at break} = \frac{\text{breaking load lbs.}}{\text{C.S.A.}}$$

C.S.A. = Sample cross sectional area.

$$\text{Percent elongation} = \frac{L - L_o \times 100}{L_o}$$

L = Sample length at break

L_o = Original length

Record data on data sheets. Also record the appearance of break (i.e., clean or fuzzy). Repeat the test on six samples that have been stored for 24 hours at 70°C in cell electrolyte CO_2 free atmosphere. Record data on data sheets. The vendor may suggest alternate methods to Philco-Ford for approval. (See Note 6.4)

20.3 Extractable Organic Content.- At least one sample shall be analyzed for soluble organic material. The sample size shall be 10 cm square. The following method of extraction of organics is recommended. If a different method is used, it shall be submitted to Philco-Ford for approval.

a. Weigh the separator sample on an analytical balance.

b. Determine volume of separator sample.

c. Put the sample in a weighed container with methanol, reagent grade. Use a volume ratio of 20 solvent to one of separator. Cover container.

d. Stir with a magnetic stirrer for a minimum of 16 hours and/or maximum of 24 hours.

e. Remove separator sample and weigh after drying.

f. Evaporate solvent.

APPENDIX A

20.3 Extractable Organic Content (Cont'd)

g. Determine weight of residue and weight loss of separator.

h. Perform IR analysis of residue. Submit copy of IR trace to Philco-Ford SRS and indicate major organic constituents. (If a larger residue sample is required to perform this task, a proportionally larger sample is permissible.)

i. Record data on the 20.3 portion of the data sheet.

Note: Specification requirement - less than 2.0 percent by weight of total organics.

20.4 Inorganic Content.- At least one sample shall be analyzed for inorganic materials. The sample size from which inorganics are to be extracted shall be a 10 cm square. Quantitative analysis of the following will be determined: carbonate, silica, zinc, chloride, nitrate, and nickel titanium. Submit a description to Philco-Ford of the method used. Record data on the sample data sheets.

Note: Specification requirement - less than 1.0 percent by weight of total inorganics as determined by ignition residue.

20.5 Discoloration of Samples in Electrolyte.- During testing of samples requiring equilibration in electrolyte, report any discoloration of the sample on the 20.5 portion of the data sheets.

20.6 Thickness Variation.- The separator thickness shall be measured at minimum intervals of one measurement for each 20 cells constructed. Each measurement shall be made on samples of two feet in length, taking 10 thickness readings at approximately two inch intervals. The gauge described in 20.1 shall be used. Record data on the sample data sheets.

20.7 Separator Materials Used in Cell Formation.- Apply the sampling criteria and test procedures specified in 20.3 and 20.4 for the separator used in cell formation. Record data in a manner similar to that delineated under 20.3 and 20.4 on the data sheets. Where applicable, furnish data on the 20.7 portion of the data sheets.

APPENDIX A

20.8 Separator Resistance.- DC method. The resistance of three samples of separator material shall be measured. Each sample shall be cut from a different roll. This method is essentially that described by Lander in Chapter 6a of the Cooper-Fleischer Handbook.

The cell used is a modification of that used in the AC method. The platinized platinum current electrodes are replaced by disc cadmium electrodes (capacity 0.7 A-hr) which are maintained in a partially discharged state. The voltage drop across the membrane is measured using two Hg/HgO reference electrodes which fit into ports in either cell half. The bottom of each port is connected by a diagonally drilled capillary to the membrane surface.

Equilibration technique and sample size are the same as in the AC method. The sample is introduced between the cell halves and the cell promptly filled with electrolyte and the reference electrodes placed. Current is passed by means of a constant current source to give 50 ma/cm^2. The voltage drop is measured between the two reference electrodes using either an electrometer or a potentiometer. A blank determination is made and substracted from the cell resistance with the membrane in the path.

(a) Calculations-

(1) Separator resistance

$$R'' = \frac{E_r - E_b}{I} A$$

R'' = Separator resistance ohm-cm^2

E_r = Voltage drop between Hg/HgO electrodes with separator in path - volts

E_b = Voltage drop between Hg/HgO electrodes with separator out of path - volts

I = Current - amperes

A = Separator area exposed cm^2

(b) Separator specific resistivity-

$$P'' = \frac{R''}{t_w}$$

P'' = Separator specific resistivity ohm-cm

R'' = Separator resistance ohm-cm^2

t_w = Equilibrated separator thickness cm

APPENDIX A

20.9 Separator Wettability.- Separator wettability of three samples of separator material shall be measured. Each sample shall be cut from a different roll. Separator wettability shall be measured by placing the dry separator sample in the resistivity cell, filling the cell with electrolyte, and recording the time required to attain a stable resistance. Measurements shall be made at five second intervals. Plot the date of the three determinations on one graph, 10 x 10 to the inch.

APPENDIX A

TEST DATA SHEET (1 of 13)

SEPARATOR TEST PROCEDURE

Note: The following information shall be supplied on each cell lot production.

Separator Material Supplier:

Base Material:

Fiber Manufacturer:

Part No.

Log No.

Date of Mfg. (mo/yr)

Separator Supplier's Style No.

Lot No.

Date of Mfg.

Material Slitted by:

(Do not use anti-static agent)

Finishes or Wetting Agents Added by Separator Supplier

Yes ____________

No ____________

Finishes or Wetting Agents Added by Cell Manufacturer

Yes ____________

No ____________

State Type of Wash and Number of Times Separator Washed

Nominal Thickness

Maximum Thickness

Minimum Thickness

APPENDIX A

TEST DATA SHEET (2 of 13)

SEPARATOR TEST PROCEDURE - (Continued)

Finishes or Wetting Agents Added by Cell Manufacturer

Yes ___________

No ___________

State type of wash and number of times separator washed

Nominal Thickness

Maximum Thickness

Minimum Thickness

1.0 Weight (gm/m^2)

Sample 1 __________ Sample 2 __________ Sample 3 __________

Applicable Philco-Ford P. O. # ______________________

Above tests conducted by ______________________ Date ____________

Prepared by ______________________ Date ____________

APPENDIX A

TEST DATA SHEET (3 of 13)

20.1 Electrolyte Absorption, Dimensional Charge, Electrolyte Retention and Porosity.-

20.1.1 Dimensions and Dimensional Changes.-

	Length (cm)		Width		Thickness	
	Dry	Wet	Dry	Wet	Dry	Wet
Sample 1						
2						
3						
4						
5						
6						

	Percentage Change in Thickness	Wet Volume (V_W)
Sample 1		
2		
3		
4		
5		
6		

20.1.2 Weight (gm/m^2).-

Sample 1 ________ Sample 2 ________ Sample 3 ________

Applicable Philco-Ford P.O. #________________

Above tests conducted by ________________ Date ________________

Prepared by ________________ Date ________________

APPENDIX A

TEST DATA SHEET (4 of 13)

20.1.3 Electrolyte Absorption.-

	Dry Weight (gm) W_D	Wet Weight (gm) W_W	Grams of Electrolyte Absorbed $(W_W - W_D)$ W_A
Sample 1			
2			
3			
4			
5			
6			

20.1.4 Electrolyte Retained.-

	Dry Weight (gm) W_D	Wet Weight (gm) W_r	Grams of Electrolyte Absorbed $(W_W - W_D0$ W_R
Sample 1			
2			
3			
4			
5			
6			

Applicable Philco-Ford P.O. # ____________

Above tests conducted by ____________ Date ____________

Prepared by ____________ Date ____________

APPENDIX A

TEST DATA SHEET (5 of 13)

20.1.4 Electrolyte Retained.- (Continued)

Calculate percent electrolyte retained from the following:

$$\frac{W_R}{W_A} \times 100 = \text{Percent Electrolyte Retained}$$

W_R = Grams of Electrolyte Retained

W_A = Grams of Electrolyte Absorbed

Percent Electrolyte Retained

Sample 1

2

3

4

5

6

20.1.5 Porosity.- Porosity or internal void volume is calculated by the following:

$$\frac{W_W - W_D}{V_W \times p} = \text{Percent Porosity}$$

Applicable Philco-Ford P.O. #________________

Above tests conducted by ________________ Date ________

Prepared by ________________ Date ________

APPENDIX A

TEST DATA SHEET (6 of 13)

20.1.5 Porosity.- (Continued)

Where

W_W = Wet weight of separator (gm)

W_D = Dry weight of separator (gm)

V_W = Wet volume of separator (cc)

p = Density of absorbed electrolyte. The density of the absorbed electrolyte is taken to be the same as the density of the equilibrating electrolyte.

Percent Porosity

Sample 1

2

3

4

5

6

Applicable Philco-Ford P.O. # ____________________

Above tests conducted by ____________________ Date __________

Prepared by ____________________ Date __________

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APPENDIX A

TEST DATA SHEET (7 of 13)

20.2 Tensile Strength.-

20.2.1 Tensile Strength at Break.-

	Tensile Strength at Break Lbs/Cm^2	Percent Elongation	Appearance of Break	Temp. Degrees^oC
Sample 1				
2				
3				
4				
5				
6				

Applicable Philco-Ford P.O. #________________

Above tests conducted by ________________ Date ________

Prepared ________________ Date ________

20.3 Determination of Organics.-

	Sample 1	2	3
Weight of separator before extraction (gm)			
Weight of separator after extraction (gm)			
Weight loss (gm)			
Weight of container plus residue (gm)			
Weight of container (gm)			

Percent organics (weight of residue divided by weight of separator after extraction) x 100 ________________

Applicable Philco-Ford P.O. #________________

Above test conducted by ________________ Date ________

Prepared by ________________ Date ________

APPENDIX A

TEST DATA SHEET (8 of 13)

20.4 Determination of Inorganics.-

	Inorganic	Percent
Sample 1		
2		
3		

20.5 Discoloration of Samples in Electrolyte.- Discribe color change and in which test discoloration occurred.

20.6 Thickness Variation.-

Reading*	Sample									
	1	2	3	4	5	6	7	8	9	10
1										
2										
3										
4										
5										
6										

Applicable Philco-Ford P.O. #____________________

Above tests conducted by ____________________ Date ____________

Prepared by ____________________________ Date ____________

*Circle maximum and minimum value for each sample.

APPENDIX A

TEST DATA SHEET (9 of 13)

20.6 Thickness Variation. - (Continued)

Reading*	Sample									
	1	2	3	4	5	6	7	8	9	10
7										
8										
9										
10										

20.7 Separator Material Used in Cell Formation.-

20.7.1 Dimensions and Dimensional Changes.

	Length (cm)	Width	Thickness
	Dry	Dry	Dry
Sample 1			
2			
3			
4			
5			
6			

Applicable Philco Ford P.O. # ______________

Above tests conducted by ______________ Date ________

Prepared by ______________ Date ________

* Circle maximum and minimum value for each sample

APPENDIX A

TEST DATA SHEET (9 of 13)

20.6 Thickness Variation. - (Continued)

Reading*	Sample									
	1	2	3	4	5	6	7	8	9	10
7										
8										
9										
10										

20.7 Separator Material Used in Cell Formation.-

20.7.1 Dimensions and Dimensional Changes.

	Length (cm)	Width	Thickness
	Dry	Dry	Dry
Sample 1			
2			
3			
4			
5			
6			

Applicable Philco Ford P.O. # ______________

Above tests conducted by ______________ Date ________

Prepared by ______________ Date ________

* Circle maximum and minimum value for each sample

APPENDIX A

TEST DATA SHEET (10 of 13)

20.7.1 Dimensions and Dimensional Changes. - (Continued)

	Percentage Change in Thickness
Sample 1	
2	
3	
4	
5	
6	

Electrolyte Absorption

	Dry Weight (gm) W_D	Wet Weight (gm) W_W	Grams of Electrolyte Absorbed (W_W-W_D) W_A
Sample 1			
2			
3			
4			
5			
6			

Applicable Philco Ford P.O. # ____________ Date ________

Above tests conducted by ____________ Date ________

Prepared by ____________ Date ________

PHILCO Ford
PHILCO-FORD CORPORATION
WDL Division · 3939 Fabian Way
Palo Alto, California · 94303

TEST DATA SHEET (11 of 13)

20.7.2 Electrolyte Retained.

	Dry Weight (gm) W_D	Wet Weight (gm) W_r	Grams of Electrolyte Retained $(W_r - W_D)$ W_R
Sample 1			
2			
3			
4			
5			
6			

Calculate percent electrolyte retained from the following:

$$\frac{W_R}{W_A} \times 100 = \text{Percent Electrolyte Retained}$$

W_D = Grams of Electrolyte Retained

W_A = Grams of Electrolyte Absorbed

Applicable Philco Ford P.O. # ______________ Date ________

Above tests conducted by ______________ Date ________

Prepared by ______________ Date ________

WDL-572B (4-69)

C-3

TEST DATA SHEET (12 of 13)

20.7.2 Electrolyte Retained. - (Continued)

Percent Electrolyte Retained

Sample 1

2

3

4

5

6

20.7.3 Porosity. - Porosity or internal void volume is calculated by the following:

$$\frac{W_W - W_D}{V_W \times p} = \text{Percent Porosity}$$

where

W_W = Wet weight of separator (gm)

W_D = Dry weight of separator (gm)

V_W = Wet volume of separator (cc)

Applicable Philco Ford P.O. # ________________

Above tests conducted by ________________ Date __________

Prepared by ________________ Date __________

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APPENDIX A

TEST DATA SHEET (13 of 13)

20.7.3 Porosity. - (Continued)

p = Density of absorbed electrolyte. The density of the absorbed electrolyte is taken to be the same as the equilibrating electrolyte.

20.7.4 Plot data of the three determinations on one graph, 10 x 10 to the inch.

20.7.5 Tensile Strength at Break.

	Tensile Strength at Break lbs/cm^2	Percent Elongation	Appearance of Break
Sample 1			
2			
3			
4			
5			
6			

Pore Volume 0.38 cc/GM

Applicable Philco Ford P.O. # ____________

Above tests conducted by ____________ Date ________

Prepared by ____________ Date ________

APPENDIX B

ELECTRODE ASSEMBLY

10. SCOPE

This appendix details the production processing and test operations on cell electrode assemblies.

20. GENERAL

20.1 Atmospheric Environment. - The environment of the formation facility shall be monitored with respect to humidity and temperature.

20.2 Handling of Materials. - All plates, separators and materials shall be handled with gloves and shall be sealed in clean room grade plastic bags when not being processed.

30. CELL FORMATION

30.1 Cell Assembly Formation Procedure.

30.1.1 Formation Cell Identification. - Sufficient numbers of previously inspected positive and negative electrodes constituting a cell pack shall have a formation cell identification number assigned. Formation cell identification numbers shall be referred to for all data recording during formation. Numbers shall be visible on each formation cell.

Note: All internal cell components shall be handled with lint-free cotton gloves. Good housekeeping procedures are required. The cell assembly shall be blown clean by a stream of air.

30.1.2 Inspection and Weighing of Electrode Assemblies. - Inspection on each electrode shall be performed in accordance with 3.1.3.1 of the specification. Particular attention shall be given to bent corners on grid and blisters on sintered material. Positive, negative and auxiliary electrode for each cell shall be grouped and the weight per cell shall be recorded to the nearest 0.1 gram.

30.1.3 (Weld Plates to Combs). - Plates shall be stacked and welded. Welds shall be in accordance with specification MIL-W-8611 if applicable and shall be reasonably free of oxidation upon visual inspection. Welds shall be inspected for burn through of plate grid or comb and inspected for loose materials. Alignment of plate edges utilizing an alignment gage shall be performed.

30.1.4 Plate Stack Wrap (Separator Material). - Separator shall be tested in accordance with 3.1.2.1 of the specification. Lot number and type of separator material shall be recorded on cell data sheets. Alignment of plate edges utilizing an alignment gage shall be performed.

APPENDIX B

30.1.5 Resistance Test of Plate Stack Assembly.- Electrode assemblies shall be compressed to the minimum internal case thickness, (tolerance +0, -2% internal percent.) The maximum compressive load shall be specified by the seller. While under compression, minimum resistivity, (at 50 VDC) shall be 100 megohms. Cells not meeting this criteria shall be identified and not reworked more than once.

NOTE: Controlled periodic calibration required if conducted on a test jig.

30.1.6 KOH Fill.- KOH shall be prepared and tested in accordance with 50.3 of Appendix C. Data from batch card on cell sheet shall be recorded. Each cell with dust cap shall be weighed to the nearest 0.1 gram before KOH is added. Contamination of KOH shall be prevented by utilizing burets while filling and by minimizing KOH exposure to atmospheric conditions. The amount of KOH shall be specified by the vendor. Formation cells shall not be subject to electrical testing for a minimum of 20 hours after KOH activation.

30.1.7 Cell Weight.- Each cell shall be weighed immediately after fill and the dust cap installed to fill tube. Cell weight with dust cap shall be recorded to the nearest 0.1 gram. Weight gain must be within +3 percent of nominal value specified by seller.

30.1.8 Cell Closure.- Depending on the manufacturers cell processing a pre-tested valve or gage assembly shall be installed on each cell within 10 minutes of filling operation. Cells left unsealed longer than 10 minutes after being filled shall be rejected. Immediately after installation of the gage assembly, cells shall be evacuated to 20 inches minimum gage vacuum. All fittings, gages and associated components of the gage assembly shall be constructed with noncorrosive stainless steel. Jackets must be put on cells ensuring surface of plates are parallel, then torqued to a specified value.

APPENDIX B

30.1.9 Leak Test of Cell and Gage Assembly.- After the gage assembly has been installed the leak rate of the cell-gage assembly shall be established prior to further processing and within one hour of cell evacuation. The cell shall be backfilled with 10 percent of volume helium and placed in a veeco to measure its leak rate. The leak rate shall be recorded and shall not exceed 10^{-5} cc/s ec. If minimum rate cannot be established, a repeat of test with another gage assembly is permitted provided care is exercised in refitting gage assembly. The cell shall be evacuated to a 25 inch vacuum or greater and the valve closed as soon as vacuum is obtained.

NOTE: The integrity of this seal condition is to be maintained through all tests prior to pinch of fill tube. Any intentional or accidental opening of assembly during electrical testing without Philco-Ford approval is reason for rejection of this cell.

30.1.10 Formation and Capacity Determination.-

30.1.10.1 Operational Conditions.- The following conditions shall be observed during operations associated with 30.2.9.

a. Charge and discharge times shall be maintained as specified by vendor within ±1.5 percent of designated time periods.

Note: 1. Exact time of each charge and each discharge shall be recorded to nearest minute. Deviation from periods specified shall be subject to immediate Philco-Ford notification and joint Material Review Board action.

2. In case of power failure, a notation shall be made and shall be clearly visible in a manner similar to that delineated on the sample data sheets.

b. Where constant currents for charge or discharge are specified, and/or current measurements are used for calculations of ampere hour capacity, currents shall be regulated within ±1.0 percent of specified value.

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APPENDIX B

30.1.10.1 Operational Conditions.- (Continued)

c. Positive and negative current leads of each formation series circuit shall have an ammeter inserted in series with each lead. One ammeter shall be marked "Control"; the second ammeter marked "Monitor". Readings of two meters shall always be within ±1.0 percent. If separate and isolated power supplies are used for each electrical string, one ammeter per string will be sufficient.

d. Voltage of each formation cell, and current of series formation circuit measurements shall be made not more than five minutes prior to end of all charge or end of all discharge periods.

30.1.10.2 Cell Formation.- Formation shall be performed in accordance with vendors schedule. Exceptions to certain operations are listed below and apply to all cells manufactured herein. The following steps shall be adhered to during the final capacity determination of positive electrodes and setting of relative state-of-charge of cadmium electrodes. The formation cell assembly shall contain the same number of plates as in the final assembly.

30.2 Cell Electrical Operation.- A minimum of 20 hours shall have elapsed before start of the electrical operation procedures. Philco-Ford shall be notified if any retest or deviation from this procedure is required. All data shall be recorded on the data sheets.

30.2.1 General.- All cells shall come from one cell lot, constructed at the same time using identical assembly techniques and components from one single batch.

30.2.2 Temperature Requirements.- During the cell electrical operations process, the average cell temperature shall be between 21°C and 27°C.

APPENDIX B

30.2.3 Electrical Operation Procedure.-

a. Discharge cell at 1.5 amps to a 1.0 volt cutoff voltage. Record time, capacity and pressure.

b. Charge each cell at 1.5 amps until a voltage of 1.60V per cell is reached. At the end of the charge, record the voltage, the pressure* and the results of an alkali leak detection*, hereafter referred to as phenolphthalein or phenol check, which shall show no red indication.

1. Maximum charge time shall be 7.0 hours.

2. Minimum charge time shall be 5.0 hours.

c. Discharge at 1.5 amps to 1.0 volt per cell. Record time, capacity and pressure*:

1. Minimum capacity shall be 3.6 ampere hours

2. Maximum capacity shall be 4.5 ampere hours.

d. Short each cell with one (1) ohm resistor for 8 hours minimum.

e. Repeat items b. through d. then charge per item b. and prepare cells for final negative electrode precharge adjustment described in Paragraph 30.2.4.

30.2.4 State of Charge Adjustment.- Precharge shall be set by a hydrogen or oxygen venting technique established by the seller. A minimum of three charge-discharge cycles are required after KOH fill as per Paragraph 30.1.6 before the precharge adjustment is made. The amount of hydrogen or oxygen removed from each cell shall have an amper-hour equivalent of 40 ±5 percent of the excess negative capacity as determined in Paragraph 30.3.1c. and 30.3.3.1. The procedure used is subject to Philco-Ford approval.

30.2.5 Cell Selection Requirements.- All cells purchased herein are subject to cell selection criteria. Whenever cells are purchased as single units in contract to complete batteries, the applicable capacity selection criteria are hereby modified as follows:

a. The total number of cells purchased shall be considered as one battery assembly (±.1 ampere hour) for capacity matching criteria.

*Note: Leak detection and pressure is not applicable to some cell processes.

APPENDIX B

30.3 Electrode Capacity Test.-

30.3.1 Sampling Rate.-

a. A minimum of two cells from each formation group of 65 cells (or less) shall be random selected prior to the formation operation and subject to a positive and negative electrode capacity test. The test cell(s) shall be fabricated with formation hardware to standard cell core configurations. The cell(s) shall be flooded with standard KOH solution. Test shall be performed as soon as possible, but prior to activation of cells of this particular formation group.

b. A minimum of one cell from each formation group of 65 cells (or less) shall be random selected prior to the precharge adjustment operation per Paragraph 30.2.3c. and then subject to a positive and negative electrode capacity test. The cell(s) shall be activated with the standard type and quantity of KOH. The addition of electrolyte is not allowable.

c. A minimum of one cell from each formation group of 65 cells (or less) shall be random selected at the conclusion of the precharge operation and subject to a residual negative electrode capacity test. The test cell(s) shall be fabricated with hardware to standard cell core configurations. The cell(s) shall be activated with the standard quantity of KOH solution. Test shall be performed as soon as possible, but prior to sealing of cells of this particular formation group.

d. A minimum of one cell from each formation group of 65 cells (or less) shall be random selected at the completion of the standard acceptance tests and then shall be subject to a residual negative electrode capacity test. Following the standard acceptance test discharge at 24°C, the test shall be performed on sample cell prior to any pinch-off tube closure of formation cells from which sample was taken.

APPENDIX B

30.3.2 Applicable Conditions.- The following conditions are applicable:

a. Cell temperature shall be between 21°C and 27°C.

b. Cell terminal voltage shall be recorded.

c. Voltage from both positive and negative terminals to the reference electrode shall be recorded continuously or at intervals not to exceed 15 minutes.

NOTE: Since the cell is in a stainless steel container, and both electrode terminals are insulated from the container, the container itself may be used as a rough substitute for a reference electrode. Even though the container potential is a function of the pressure O_2 or H_2 in the cell, the changes in electrode voltage at end of capacity are relatively large and usually can be clearly identified using the container as a reference.

30.3.3 Test Procedure.-

30.3.3.1 Residual Negative Electrode Capacity.- The cell shall be discharged to 0 volt at 1.5 amp rate. Then discharge at 1.5 amperes until terminal voltage indicates -1.0 volt. Terminal (cell) voltage and voltage from both positive and negative terminals to reference electrode shall be recorded. The measured residual negative electrode capacity shall meet the requirements specified in Table I.

30.3.3.2 Charge.- Cells shall be charged at 1.5 amperes for a minimum period of 5 hours until a cell voltage of 1.60 volts is reached A maximum period of 7 hours shall not be exceeded. Cell and reference cell voltages shall be recorded continuously or at intervals not to exceed 1 hour.

APPENDIX B

30.3.3.3 Discharge.- Cells shall be discharged at 1.5 amperes until terminal voltage indicates -1.0 volt. Positive and negative terminal to reference voltages shall be time recorded when the cells' terminals reach:

a. +1.0 volt

b. +0.5 volt

c. 0.0 volt

d. -0.5 volt

e. -1.0 volt

The positive and negative electrode capacities measured during this test shall meet the capacity requirements delineated in Table I.

NOTE: The cells shall be protected from further contact with the atmosphere in the event further testing is required.

APPENDIX B

30.3.3.4 Calculations. -

Let

(T_{N_1}) = Time to -1.0 V (as delineated in 30.3.3.1)

= Time to discharge precharged negative

(T_{P_3}) = Time from start of discharge (full charge) to +0.0 V (as delineated in 30.3.3.3)

= Time to discharge positive electrode

(T_{N_3}) = Time to -1.0 V (as delineated in 30.3.3.3)

= Time to discharge total negative electrode

I_0 = Discharge current = 1.5 amperes

Then

$I_0 \left[(T_{N_3}) - (T_{P_3}) \right]$ = Excess capacity of total negative over positive

$I_0 \left[(T_{N_1}) \right]$ = Precharged negative capacity

$I_0 \left[(T_{N_3}) - T_{P_3} - T_{N_1} \right]$ = Excess (discharged) negative capacity at the charged end

$\dfrac{(T_{N_3})}{(T_{P_3})}$ = "Negative-to-Positive Ratio"

30.3.3.5 Submittal of Data. - Two copies of all information obtained shall be submitted to Philco-Ford prior to further processing.

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APPENDIX C

10. SCOPE

This appendix details the processing operations on tests required for insulating, brazing, welding, plating, filling and testing of cells.

20. CERAMIC MATERIAL

The ceramic material shall be alumina of 99.65 $\pm$ 0.25 percent purity.

20.1 Mechanical Inspection.-

a.	Dimensions -	Sampling 2.5 A.Q.L.
b.	Chips, cracks, gain structure (uniform density), voids -	100 percent inspection

20.2 Cleaning.- Components shall be cleaned by ultrasonic bath using freon.

30. COVER ASSEMBLY

30.1 Cleaning.- Chemical cleaning shall be utilized on all parts and a combination of chemical cleaning and furnace firing shall be utilized on cup and collar to prepare them for vacuum brazing.

30.2 Welding of Pinch Tube to Cover.- Welding of pinch tube to cover shall be controlled by a process specification to insure adequate weld strength and seal integrity or may be tested as an integral part of the cover.

30.3 Inspection.- The cover shall be 100 percent inspected for cracks, porosity, excessive burning, oxidation and foreign inclusions. 100 percent inspection shall be performed on all pinch tube cover welds and they shall be capable of passing a helium leak test (leak rate - 1×10^{-8} std cc/sec). Samples shall be tested periodically for weld quality by metallurgical sectioning.

30.3.1 Assembly Fixturing.- Mechanical fixturing shall be adequate to insure maintenance of part positions during brazing operation. Self-jigging features shall be included where possible. Particular attention shall be paid to alignment of terminal post and ceramic to maintain concentricity. Provisions for periodic cleaning of fixture shall be made.

APPENDIX C

30.4 Vacuum Braze Operations.- Processes shall be established which ensure clean handling of parts and fixtures. A brazing inspection plan shall be submitted by seller subject to mutual approval.

30.5 Visual Inspection.- All units shall receive inspection of terminal location, seal junction continuity, braze joint quality, pinholes, and flowout shall be visually inspected using magnification aids where required.

30.6 Insulator Resistance.- All units shall receive an insulation check. Each unit must exhibit resistance above 100 megohms at 50 VDC.

30.7 Leak Check.- The complete cover assembly shall pass a 100 percent sample leak check of 1×10^{-8} cc/sec of helium.

30.8 Nickel Plating.

30.8.1 Fixture.- The cover assembly shall be mounted in a fixture designed to prevent access of plating solutions to a ceramic-metal terminal well.

30.8.2 Cover Assembly Preparation.- Cover assembly preparation shall consist of hydrohone and washed in water, then dryed.

30.8.3 Inspection Criteria.

a. Plating Thickness: Plating thickness shall be checked by 2.5 AQL sampling. Thickness shall be measured with magna-gage or equivalent. Any part outside of limits shall be rejected.

b. Plating Quality: Blisters shall be checked by 100 percent sampling. Adhesion shall be checked by 2.5 AQL sampling using test tape.

c. Corrosion: Corrosion shall be checked by 100 percent sampling. All cover assemblies shall be checked for evidence of plating solution leakage following removal of the fixture. Any stains or evidence of wetness on the cover surface in the vicinity of the ceramic-terminal post seal shall be cause for rejection. A 5 percent sample of finished assemblies shall be subjected to a halide test. Any evidence of halide shall cause 100 percent of the lot to be subjected to the test. All samples showing positive halide shall be rejected.

d. After completion of cell assembly the resistance shall be measured using a megohmeter applying 50 VDC as follows:

1) + terminal to - terminal, resistance shall be 100 megohms or greater.

30.8.3 Inspection Criteria (Cont'd)

d. (continued)

2) (+) terminal to case, resistance shall be 5 megohms or greater.

3) (-) terminal to case, resistance shall be 5 megohms or greater.

40. TINNING OF TERMINAL LUGS

Both positive and negative terminal lugs shall be tinned prior to welding header to case. Prevention of flux from entering the terminal pockets shall be accomplished by applying EC1663 between post and ceramic. During dip in flux, cell header shall be inverted. (terminals down). (See Note 6.4).

40.1 Cleaning of Terminals After Tinning.-

a. After pre-tinning, posts shall be washed with running hot water (44°C) and scrubbed thoroughly during this wash for a minimum of 30 seconds using a nylon tooth brush or test tube brush.

b. Terminal area shall be dipped in a solution of 5 percent ammonium hydroxide and posts immersed for a minimum of 10 seconds.

c. Rinse with water.

d. Rinse in acetone.

e. Place under a minimum vacuum of 25 inches Hg.

40.2 Analytical Check for Flux Traces.- A standard fluoride-chloride test (silver nitrate) shall be conducted as follows:

a. Pour 40 cc of boiling distilled water over the terminal areas and collect water in a beaker.

b. Conduct a standard fluoride-chloride test on this collected water.

c. If the analytical check is negative (showing absence of fluoride-chloride traces), the EC1663 potting can be removed and the cell can go to the next production step.

d. If the analytical check is positive (showing presence of fluoride-chloride traces), repeat steps a through e of 40.1.

APPENDIX C

50. CONTROL AND TESTING OF WATER AND ELECTROLYTE

This electrolyte solutions and wash water used for cells specified herein shall be of high purity. Two copies of all data obtained herein shall be submitted to Philco-Ford for further processing.

50.1 Deionized Water.- Deionized water used in all wash water, dilutant, or additive shall have a resistivity of greater than 1.0 megohm-cm. In the event the resistivity drops below 1.0 megohm-cm, the process shall be stopped until the resistivity is restored to the specified limits. The resistivity is to be determined prior to each operation in which the water is used.

A suitable conductivity cell calibrated less than two weeks prior to start of water requirement tests used on cells constructed under this specification shall be used. Criteria for calibration shall be as follows:

a. The conductivity cell shall be re-calibrated at two week intervals (maximum) until completion of the water requirement tasks.

b. The calibration shall be conducted in a 0.1 percent potassium chloride solution and shall record a conductivity of 1410 $\pm$ 20 micromos at 25°C (a temperature correction as per the handbook of chemistry and physics may be used). If conductivity is not within these tolerances, the conductivity cell must be replaced or replatinized.

c. The silica content in the water shall not exceed 1 ppm.

d. The solids content of the water must be determined by the seller. The maximum solids shall not exceed 50 ppm.

50.2 Distilled Water.- Distilled water used either as wash water, dilutant or additive shall be tested and shall meet the requirements of 50.1.c and d above.

50.3 Electrolyte.- The supplier, batch number, grade analysis, date of purchase and date container is opened must be recorded. The potassium hydroxide "mercury cell grade"electrolyte concentrate as defined by Allied Chemical Company or equivalent, shall be mixed with the distilled water to make-up a solution with a tolerance of $\pm$ 0.5 baume. Each batch of electrolyte shall be analyzed for carbonate content and hydroxyl ion concentration using the double titration method of phenolphthalein end point followed by methyl purple or orange end point. Carbonate concentration must be less than (2.8 gms/liter) The hydroxyl ion concentration shall be determined by analytical methods. The concentration tolerance of KOH shall be $\pm$ 20 mg/cc. The electrolyte shall be analyzed for nitrate content. The tolerable level is 1 mg/liter nitrate or less, using a commercially available ion selective electrode. The shelf life of the standard acid used in this titration shall not have been exceeded.

APPENDIX F

EAGLE PICHER CELL MANUFACTURING FLOW PROCEDURE EP-QC-810

BATTERY TRAVELER

for

RSN-3 Flow Sheets

DATE	REVISION	APPROVAL
10/7/74	A	LJK

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EAGLE-PICHER INDUSTRIES, INC.
Electronics Division
Couples Department
Joplin, Missouri

RSN-3 Flow Sheets — Lot No.______________

	Operator	Inspector
1.0 POSITIVE ELECTRODE		
Positive Plaque Lot Number________		
1.1		
1.2 Cut plates per Dwg. 60-30-585-1, Rev.____	________	
1.3 Punch plates per Dwg. 60-30-585-1, Inspect per IIS #5.	Date______________	Q.C.
1.4 Weigh and sort plates per EP-QC-838, Rev._____.	________	
1.5 Inspect plate weight range per IIS #10, Rev.______. No. of plates inspected__________. Maximum weight__________. Average weight__________. Minimum weight__________. Number of plates accepted__________.	Date______________	GSI / Q.C.
1.6 Edge plates per Dwg. 005350 Rev._____	________	
1.7 Inspect plate tabs per IIS #20.	Date______________	GSI / Q.C.
1.8 Spot weld plate Tabs per EP-WS-10, Rev.____	________	
1.9 Inspect plate tab welds per IIS #20, Rev.______ and EP-WS-10.	Date______________	GSI / Q.C.
1.10 Press Plate Assembly per 005350, Rev. _____	________	
1.11 Inspect plates per IIS #30, Rev._____ and EP-QC-873, Rev._____	Date______________	GSI / Q.C.
1.12 Inspect storage conditions & data per IIS #30, Rev._____.	Date______________	Q.C.

EP-QC-810, Rev. A

EAGLE-PICHER INDUSTRIES, INC.
Electronics Division
Couples Department
Joplin, Missouri

RSN-3 Flow Sheets

		Operator	Inspector
2.0	NEGATIVE ELECTRODE		
	Negative Plaque Lot Number__________.		
2.1			
2.2	Cut plates per Dwg. 60-30-585-2, Rev.______.	__________	
2.3	Punch plates per Dwg. 60-30-585-2, Inspect per IIS #5.	Date__________	Q.C.
2.4	Weigh and sort plates per EP-QC-838.	__________	
2.5	Inspect plate weight range per IIS #10, Rev.______. No. of plates inspected__________. Maximum Weight__________. Average Weight__________. Minimum Weight__________. Number of plates accepted__________.	Date__________	GSI / Q.C.
2.6	Edge plates per Dwg. 005349, Rev.______	__________	
2.7	Inspect tabs per IIS #20.	Date__________	GSI / Q.C.
2.8	Spotweld plate tabs per EP-WS-10, Rev.___	__________	
2.9	Inspect plate tab welds per IIS-20, Rev.______, and EP-WS-10,	Date__________	GSI / Q.C.
2.10	Press plate assembly per 005349, Rev.______.	__________	
2.11	Inspect plates per IIS #30, Rev.______ and EP-QC-873, Rev.________	Date__________	GSI / Q.C.
2.12	Inspect storage conditions and data per IIS #30, Rev.______.	Date__________	Q.C.

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RSN-3 MANUFACTURING FLOW SHEET

CELL S/N	POS.GRP. WT. (GMS)	NEG.GRP.WT. (GMS)	CORE WT. (GMS)	POS.GRP.THK (IN.)	NEG.GRP.THK (IN.)	CORE THK. (IN.)	CELL DRY WT. (GMS)	KOH WT. (GMS)	AFTER ACT.WT. (GMS)	AFTER COND.WT. (GMS)	FINISHED CELL WT. (GMS)

DATE OF CELL GROUP ACTIVATION ________________ OPERATOR ________________

INSPECTION

EAGLE-PICHER INDUSTRIES, INC.
Electronics Division
Couples Department
Joplin, Missouri

Lot No.______________________

Operator / Inspector

RSN-3 Flow Sheets

3.0 GROUP CONSTRUCTION: Drawing #005352, Rev.______

3.1 Inspect plate storage & paperwork per IIS #40 & release plates for further assembly.

Positive Plates — Date__________________ | Q.C.

Negative Plates — Date__________________ | Q.C.

3.2 Group positive plates per Dwg. 005352, Rev. ______. __________

3.3 Inspect positive group assemblies per IIS #50, Rev.______, Item A. — Date__________________ | GSI | Q.C.

3.4 Group negative plates per Dwg. 005352. __________

3.5 Inspect negative group assemblies per IIS #50, Rev.______, Item A — Date__________________ | GSI | Q.C.

4.0 CELL ASSEMBLY

4.1 Weigh positive and negative groups for each cell & record cell serial number, group weights, & group thickness on Page 6 of 6. All weights must be recorded to the nearest 0.1 gram. __________

4.1.1 Verify that group weights meet IIS No. 50, Item C — Date__________________ | GSI | Q.C.

4.2 Degrease cell case __________

4.2.1 Inspect per IIS #40. — Date__________________ | Q.C.

4.3 Separate cell per Drawing 005352 and insert in cell case. __________

Separator Lot No.__________

Cell Case Lot No.__________

4.3.1 Pre-shape tabs per 005352.

4.3.2 Spotweld tabs per EP-WS-10. __________

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Electronics Division
Couples Department
Joplin, Missouri

RSN-3 Flow Sheets

Lot No. ______________

		Operator	Inspector		
4.3.3	Remove core from case and record core weight and core thickness on Page 6 of 8. Weight must be recorded to the nearest 0.1 grams. Return core to cell case.	________			
4.3.4	Trim tabs per Drawing 005352.	________			
4.3.5	Weld terminals per EP-WS-10.	________			
4.3.5.1	Inspect per IIS 60, Rev.___.	Date ________	GSI	P/F	Q.C.
4.4	Remove cell pack from case and clean cell case with dry nitrogen.	________			
4.4.1	Install insulator plate.	________			
4.5	Install separator jacket & install in cell case.	________			
4.5.1	Apply potting compound per 005352.	Date ________	GSI	P/F	Q.C.
4.5.2	Perform insulation resistance per IIS 60, Rev.___.	Date ________	GSI	P/F	Q.C.
4.6	Electrode Capacity Test on plates per EP-QC-839.	Date ________	GSI	P/F	Q.C.
4.7	Package per EP-MP-166, Rev.___.	________			
4.7.1	X-ray per EP-QC-840, Rev.___.	Date ________	GSI	P/F	Q.C.
4.7.2	Inspect per IIS No. 60, Rev.___.	Date ________	GSI	P/F	Q.C.
4.8	Weld cover to case per Drawing 005352.	________			
4.9	Inspect per IIS No. 60.	Date ________	GSI	P/F	Q.C.
4.10	X-Ray	Date ________	GSI	P/F	Q.C.
4.11	Install permanent serial number.	________			
4.12	Nitrogen leak check.	Date ________	GSI	P/F	Q.C.

RSN-3
Helium Leak Test
Data Sheet

Standard Rate ________

Date ________
Cell Lot No. ________

CELL SERIAL NO.	LEAK RATE	CELL SERIAL NO.	LEAK RATE

Inspector ________

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Electronics Division
Couples Department
Joplin, Missouri

RSN-3 Flow Sheets

Lot No.____________

		Operator	Inspector		
5.0	**FINAL CELL ASSEMBLY**				
5.1	Place cell lot number on all pages of flow sheet.	Date			Q.C.
5.2	One-hundred percent (100%) leak check on gauge assemblies and cells, per EP-MP-164.	Date	GSI	P/F	Q.C.
5.3	Record dry weight.	Date	GSI	P/F	Q.C.
5.4	Activate cells per EP-MP-160, Rev.___.	Date	GSI	P/F	Q.C.
5.5	Record wet weight.	Date	GSI	P/F	Q.C.
5.6	Twenty-four (24) hour vacuum leak test.	Date	GSI	P/F	Q.C.
5.7	Electrolyte leak test.	Date	GSI	P/F	Q.C.
5.8	Cell conditioning per EP-MP-160 (vented cycle).	Date	GSI	P/F	Q.C.
5.9	Perform electrode capacity test per EP-QC-839, Rev.___.	Date	GSI	P/F	Q.C.
5.10	Perform power discharge test per EP-MP-160.	Date	GSI	P/F	Q.C.
5.11	Perform electrode capacity test per EP-MP-160.	Date	GSI	P/F	Q.C.

Engineering
Data Approval____________

6.0	**ACCEPTANCE TEST PER ATP-279, Rev.___.**				
6.1	Perform twenty-four (24) hour vacuum leak test on gauge assemblies & cells per EP-MP-160.	Date	GSI	P/F	Q.C.
6.2	Capacity Discharge 24°C (overcharge).	Date	GSI	P/F	Q.C.
6.3	Capacity Discharge 35°C.	Date	GSI	P/F	Q.C.
6.4	Capacity Discharge 0°C.	Date	GSI	P/F	Q.C.
6.5	Capacity Discharge 24°C.	Date	GSI	P/F	Q.C.
6.6	Electrolyte Leakage Test.	Date	GSI	P/F	Q.C.
6.7	Charge Retention Test.	Date	GSI	P/F	Q.C.
6.8	Twenty-four (24) hour vacuum leak test per EP-MP-160.	Date	GSI	P/F	Q.C.

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Electronics Division
Couples Department
Joplin, Missouri

RSN-3 Flow Sheets

			Operator	Inspector		
7.0	FINISHED CELL PREPARATION					
	7.1	Helium leak check per EP-MP-164.	Date____	GSI	P/F	Q.C.
	7.2	Leak Test per EP-MP-164.	Date____			Q.C.
	7.3	Liquid Hone per EP-MP-158.	Date____			Q.C.
	7.4	Label per 005318, Rev.___ and EP-MP-159, Rev. ___.	Date____			Q.C.
	7.5	X-ray per EP-QC-840.	Date____	GSI	P/F	Q.C.
	7.6	Final inspection per 005318 and IIS 70, Rev. ___.	Date____	GSI	P/F	Q.C.
8.0	PACKAGING					
	8.1	Clean cells with alcohol.	Date____			Q.C.
	8.2	Connect upper shorting wire.	Date____			Q.C.
	8.3	Package per 005404, Rev.___.	Date____	GSI	P/F	Q.C.

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APPENDIX G

TEST RESULTS OF SMS BATTERY CELL PERFORMANCE EVALUATION

INTRODUCTION

This report summarizes results of special tests conducted per the test plan outlined in the reference on cells from Lots 1, 3, 5 and 6, used in assembly of the first seven batteries for the SMS Program. These tests were performed to evaluate and document the potential impact of anomalous battery performance noted during acceptance tests of Units S/N 1003 and 1004. Cells from Lot 3 used in assembly of these units were rejected for flight use after developing high internal pressures during battery acceptance tests. Two of these cells, S/N 296 and 311, were removed from these units and subjected to a series of overcharge and electrode capacity tests. Included in these tests were additional cells from the aforementioned cell lots. Cells were disassembled and examined for possible failure modes. Electrolyte and separator materials were removed from selected cells and subjected to chemical analysis. Results of these tests and other analyses performed in this evaluation are summarized in the following sections.

TEST RESULTS

Results of low and high temperature overcharge tests performed in this evaluation are included in Table 1 and Figure 1. Table 1 lists both the maximum and end-of-charge cell voltages reached during those tests. Figure 1 summarizes end-of-charge cell voltage characteristics for cell Lots 1, 3, 5 and 6 based on data listed in Table 1. Figures 2 and 3 contain results of electrode capacity tests performed on cells S/N 296 and 311. Carbonate and nitrate determinations of electrolyte and separator material removed from these and other Lot 1 and 3 cells are summarized in Table 2. Results of these tests indicate that conditions leading to the excessive pressurization of Lot 3 cells during battery acceptance tests were not simulated during low and high temperature special testing. Quantitative data relating to the most likely causes of this pressurization was obtained during electrode capacity tests and failure analysis of cells S/N 296 and 311. Since all cell lots tested in this evaluation exhibited some high voltage characteristics during low temperature overcharge tests, recommendations for low temperature battery operation were made to preclude development of excessive cell pressurization. Analysis and discussion of these results and recommendations are included in the following sections.

DATA ANALYSIS

Analysis of overcharge data summarized in Table 1 indicates that cells from Lots 3, 5 and 6 have slightly higher charging voltage characteristics at 35°C than cells from Lot 1, and that cells from Lots 5 and 6 have somewhat lower charge voltage characteristics at 2°C than cells from Lots 1 and 3. Lot 1 cells had previously been subjected to accelerated life tests, and are representative of cells used in engineering development cell and engineering model battery tests and qualification unit evaluation. Cells from Lot 3 included the aforementioned cells S/N 296 and 311, and three additional cells. One of these, S/N 281, had no previous test history other than during vendor acceptance tests. The remaining cells had been subjected to cell screening tests. Cell S/N 297 had been rejected for high charging voltage characteristics at 2°C and cell S/N 340 was considered a flight spare for Units S/N 1003 and 1004. Cells from Lots 5 and 6 were also rejected during cell screening tests. Lot 5 cells S/N 403 and 423, and Lot 6 cells S/N 490 and 512 were rejected for high charging voltage characteristics at room temperature. Lot 5 cell S/N 471 had failed charge retention tests and Lot 6 cell S/N 511 had exhibited high charging voltage characteristics at 2°C. Since no indication of excessive pressurization was observed in cells included in these special tests, a critical voltage-temperature cell pressure relationship was not identified. Lot 1 cell S/N 33 and Lot 3 cells S/N 281, 296, 311 and 340 were then disassembled and examined for possible failure modes. Results of tests and analyses performed are summarized as follows:

A. Analyses of electrode capacity test data summarized in Figures 2 and 3 indicate some degradation had occurred in the negative electrodes of Lot 3 cells S/N 296 and 311. These cells yielded relatively low levels of negative precharge (0.19 AH for S/N 296 and 0.36 AH for S/N 311). The negative to positive capacity ratio for cell S/N 296 was 1.21, indicating a loss of measurable uncharged negative capacity based on "new cell" ratio requirements of 1.50 to 1.80. No loss in positive electrode capacity was observed in this cell. This ratio was not determined for cell S/N 311 due to the fact that the cell did not reverse to (-) 1.0 volts during uncharged negative capacity tests. Since reduced levels

of uncharged negative capacity can contribute to hydrogen gas evolution during overcharge at the negative electrode, it was concluded that the degradation observed in the negative electrodes of cells S/N 296 and 311 probably contributed to the high internal cell pressures observed during battery acceptance tests of Units S/N 1003 and 1004. Possible causes of the high voltages observed in these cells during those tests are discussed in the following paragraph.

B. Failure analysis of cells disassembled and examined in this evaluation indicates that the high cell voltages previously observed in cells S/N 296 and 311 were, in part, due to high internal resistance resulting from a weakening in the cell plate tab-to-terminal spade weld. These changes probably occurred when the cell covers distorted due to internal pressures generated during high temperature battery acceptance tests. Varying degrees of brown discoloration were observed in the outer separator wrap of the five cells disassembled in this evaluation. A greater degree of separator discoloration was noted in cells S/N 296 and 311. The nylon spacer block located between the cell cover and electrode assembly of S/N 311 appeared to have, at some time, reached a temperature which caused the material to melt and flow. Since no evidence of internal shorting was found in this cell, it was hypothesized that the heat must have been introduced during cover-to-can welding of the cell. This hypothesis was based in part on the observation that separator discoloration in the disassembled cells was concentrated in areas of close contact between the separator and cell can. The nylon spacer block is located in one such area which is also close to the cell cover-to-can weld as shown in Figure 4.

C. Chemical analysis of electrolyte and separator material removed from cells disassembled in this evaluation are summarized in Table 2. The percentage of carbonate (6%) found in these cells in somewhat greater than the desired level of less than 1%. This level of contamination is

DATA ANALYSIS (Cont'd)

sufficient to have contributed to the high cell charging voltage characteristics observed during the 2°C overcharge tests. Qualitative analyses of the separator material indicate that substantial quantities of iron and cadmium are present in the outer separator wraps. It is not clear what significance can be attributed to the iron found in this analysis. Substantial levels of cadmium would be expected due to the proximity of the outer separator wrap to the negative electrodes.

CONCLUSIONS AND RECOMMENDATIONS

Although excessive cell pressurization was not observed in tests conducted during this evaluation, data was obtained which yielded background information into the most likely causes of the anomalous cell performance characteristics noted during acceptance tests of units S/N 1003 and 1004. Analysis of data indicates that excessive pressurization observed in Lot 3 cells S/N 296 and 311 during battery acceptance tests probably resulted from a combination of hydrogen and oxygen gases generated during low and high temperature battery charging. High cell charging voltage characteristics observed during low temperature acceptance tests are indicative of overcharged negative electrodes. Since electrode capacity tests on these cells showed degradation in the relative levels of uncharged negative, it was concluded that this degradation contributed to hydrogen evolution from the negative electrode during low temperature battery charging. Hydrogen does not readily recombine, therefore residual hydrogen pressure would then have been present during subsequent high temperature battery capacity tests. This residual pressure coupled with increased oxygen evolution at earlier states of charge at higher temperatures resulted in excessive cell pressurization during high temperature battery charging. The resultant pressurization caused the covers of cells S/N 296 and 311 to distort which, in turn, created a weakening in the cell plate tab-to-terminal spade weld. This resulted in increased

internal cell resistance, and thus explains the high charging voltages suddenly noted in these cells during high temperature battery charging. Subsequent failure analysis of these welds showed less than optimum fusion between the tabs and terminal spade lugs in these Lot 3 cells. Chemical analysis of electrolyte and separator materials in these cells showed a carbonate contamination level of 6% by weight. This level of contamination is sufficient to have contributed to the high cell charging voltage characteristics noted during low temperature charging. Since cells from Lots 5 and 6 used in assembly of units S/N 1005, 1006 and 1007 have not exhibited any similar type failure modes during battery acceptance tests as the rejected Lot 3 cells used in assembly of Units S/N 1003 and 1004, it was concluded that the latter three units are acceptable for flight. Based on a review of this data with NASA/GSFC personnel, it has been recommended that for orbital operation these units be commanded to trickle charge whenever battery voltages exceed 30.5 volts to preclude the development of excessive cell pressurization. This voltage limit precaution is particularly important if the actual battery temperature drops below the predicted minimum equinox battery temperature of +7°C at beginning-of-life.

As a result of the failure analysis performed in this evaluation on Lot 3 cells S/N 296 and 311, a review was conducted on welding processes used during production of Lot 7 cells by NASA/GSFC and Philco-Ford personnel. Pull tests performed on cell plate tab-to-terminal spade welds showed acceptable welds for samples taken at the beginning, during, and at completion of a typical production run. Random samples were sectioned and examined for fusion between the tabs and terminal spade lugs. Results of these tests indicated good fusion in all samples tested. Welding schedules during cell cover to can welding processes were modified to minimize cell heating, and additional holding fixtures were used during these processes to optimize cell heat sinking. Examination of a production cell showed no evidence of excessive internal heating as previously observed in Lot 3 cell, S/N 311. It was concluded that welding processes used in production of Lot 7 cells assigned for use in Units S/N 1008, 1009 and 1010 were acceptable.

TABLE 1. MAXIMUM AND END OF CHARGE CELL VOLTAGES FOR SPECIAL SMS BATTERY CELL PERFORMANCE OVERCHARGE TESTS

	CELL	FIRST 35°C TEST *		2°C TEST *		SECOND 35°C TEST *	
	S/N	MAX.VOLTAGE	EOCV	MAX.VOLTAGE	EOCV	MAX.VOLTAGE	EOCV
LOT 1	1	1.385(13)	1.380(26)	1.623(40)	1.619(46)	1.383(16)	1.375(41)
	2	1.386(16)	1.383(26)	1.593(40)	1.587(46)	1.380(16)	1.377(41)
	3	1.386(14)	1.382(26)	1.604(40)	1.597(46)	1.382(16)	1.376(41)
	4	1.390(20)	1.387(26)	1.617(41)	1.614(46)	1.384(16)	1.380(41)
	5	1.384(14)	1.378(26)	1.630(39)	1.621(46)	1.381(15)	1.376(41)
	6	1.390(17)	1.388(26)	1.614(40)	1.607(46)	1.384(17)	1.380(41)
	7	1.391(20)	1.390(26)	1.596(39)	1.588(46)	1.384(17)	1.381(41)
	8	1.389(15)	1.386(26)	1.610(40)	1.602(46)	1.384(17)	1.379(41)
	9	1.388(17)	1.386(26)	1.588(39)	1.582(46)	1.382(19)	1.379(41)
	10	1.393(20)	1.391(26)	1.626(40)	1.620(46)	1.387(19)	1.382(41)
	11	1.389(17)	1.387(26)	1.602(39)	1.594(46)	1.384(24)	1.381(41)
	12	1.392(20)	1.389(26)	1.617(39)	1.612(46)	1.386(24)	1.382(41)
LOT 3	296	1.403(21)	1.401(26)	1.578(45)	1.577(46)	1.420(26)	1.400(41)
	297	1.412(21)	1.408(26)	1.599(37)	1.593(46)	1.393(22)	1.388(41)
	306	1.415(20)	1.409(26)	1.604(37)	1.596(46)	1.394(19)	1.388(41)
	311	1.414(20)	1.412(26)	1.632(35)	1.624(46)	1.399(17)	1.400(41)
	340	1.408(20)	1.404(26)	1.613(38)	1.609(46)	1.389(21)	1.385(41)
LOT 5	403	1.420(21)	1.410(26)	1.578(37)	1.572(46)	1.398(20)	1.392(41)
	423	1.416(21)	1.409(26)	1.594(46)	1.594(46)	1.399(24)	1.392(41)
	471	1.435(20)	1.422(26)	1.567(38)	1.550(46)	1.409(21)	1.401(41)
LOT 6	490	1.423(20)	1.411(26)	1.597(38)	1.566(46)	1.403(19)	1.394(41)
	511	1.416(20)	1.410(26)	1.605(37)	1.601(46)	1.400(22)	1.394(41)
	512	1.423(20)	1.410(26)	1.589(38)	1.565(46)	1.403(18)	1.396(41)

* Numbers in parenthesis are elapsed hours of charge. 35°C tests were performed at C/10 charge rate, 2°C test at C/20 rate.

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LOT NO.	CELL S/N	SAMPLE WT.*	PELLON WT.*	NON PELLON WT.* (%)**	CO_3 WT.* (%)**	NO_3 WT.* (%)**
1	33	901	588	313 (34.8)	20 (6.4)	None detected
3	281	895	659	236 (26.4)	15 (6.4)	0.05 (0.02)
3	296	971	810	161 (16.6)	12 (7.4)	0.05 (0.03)
3	311	777	588	189 (24.4)	12 (6.3)	0.04 (0.02)
3	340	781	605	176 (22.5)	12 (6.8)	0.15 (0.09)

* WEIGHTS MEASURED IN MILLIGRAMS BY COOK RESEARCH LABORATORIES, INC., MENLO PARK, CALIFORNIA.

** NON PELLON WEIGHTS EXPRESSED AS PER CENT OF SAMPLE WEIGHTS, CARBONATE (CO_3) AND NITRATE (NO_3) WEIGHTS EXPRESSED AS PER CENT OF NON PELLON WEIGHTS. NON PELLON PORTIONS OF SAMPLES EXTRACTED WITH DEIONIZED WATER AND ANALYZED TO CONCENTRATIONS ATTRIBUTABLE TO THE TOTAL SAMPLE.

TABLE 2

CARBONATE AND NITRATE DETERMINATIONS ON SMS BATTERY CELL SEPARATOR MATERIAL

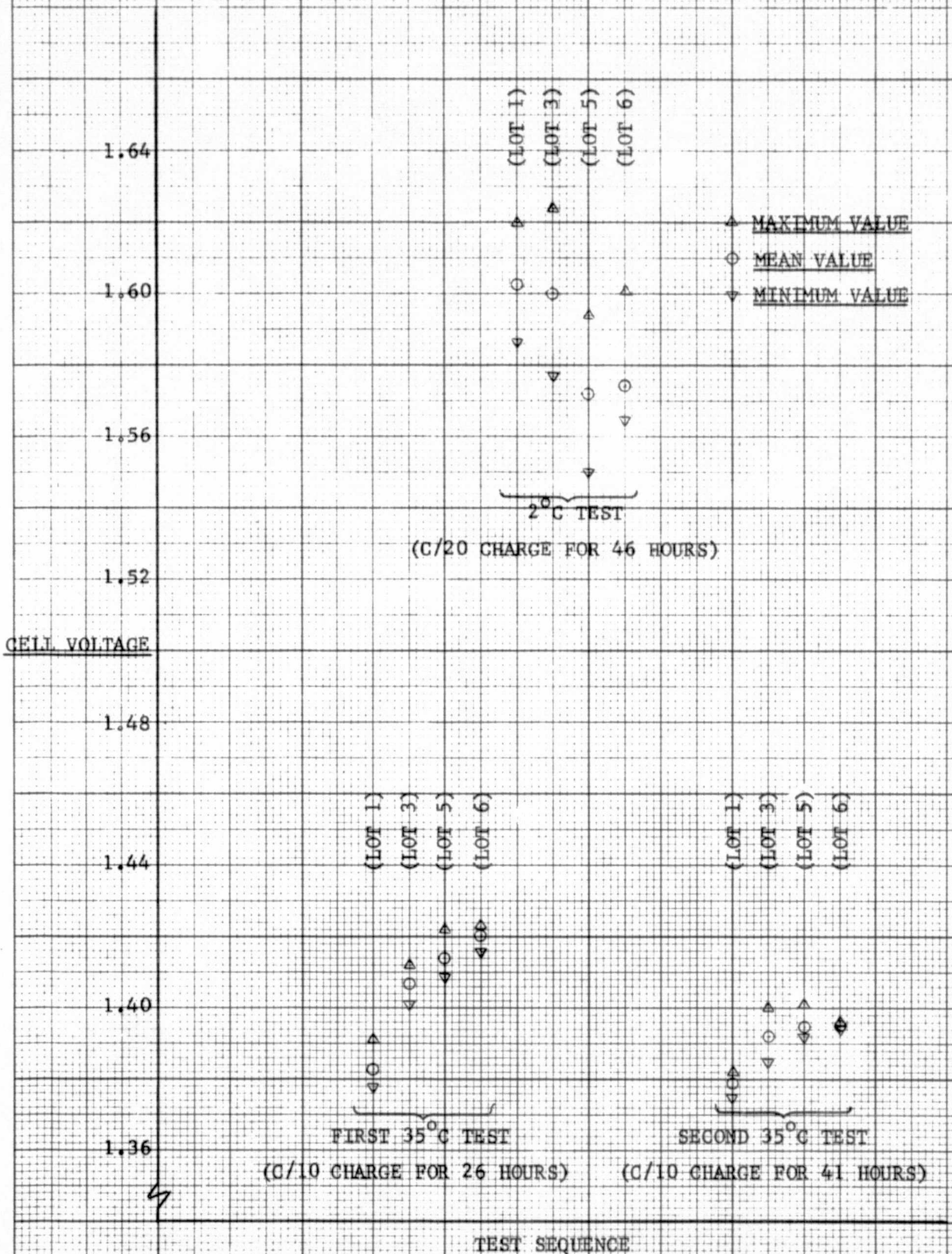

FIGURE 1. END OF CHARGE CELL LOT VOLTAGE CHARACTERISTICS FOR BATTERY CELL PERFORMANCE OVERCHARGE TESTS (SMS)

NO. 340R-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.

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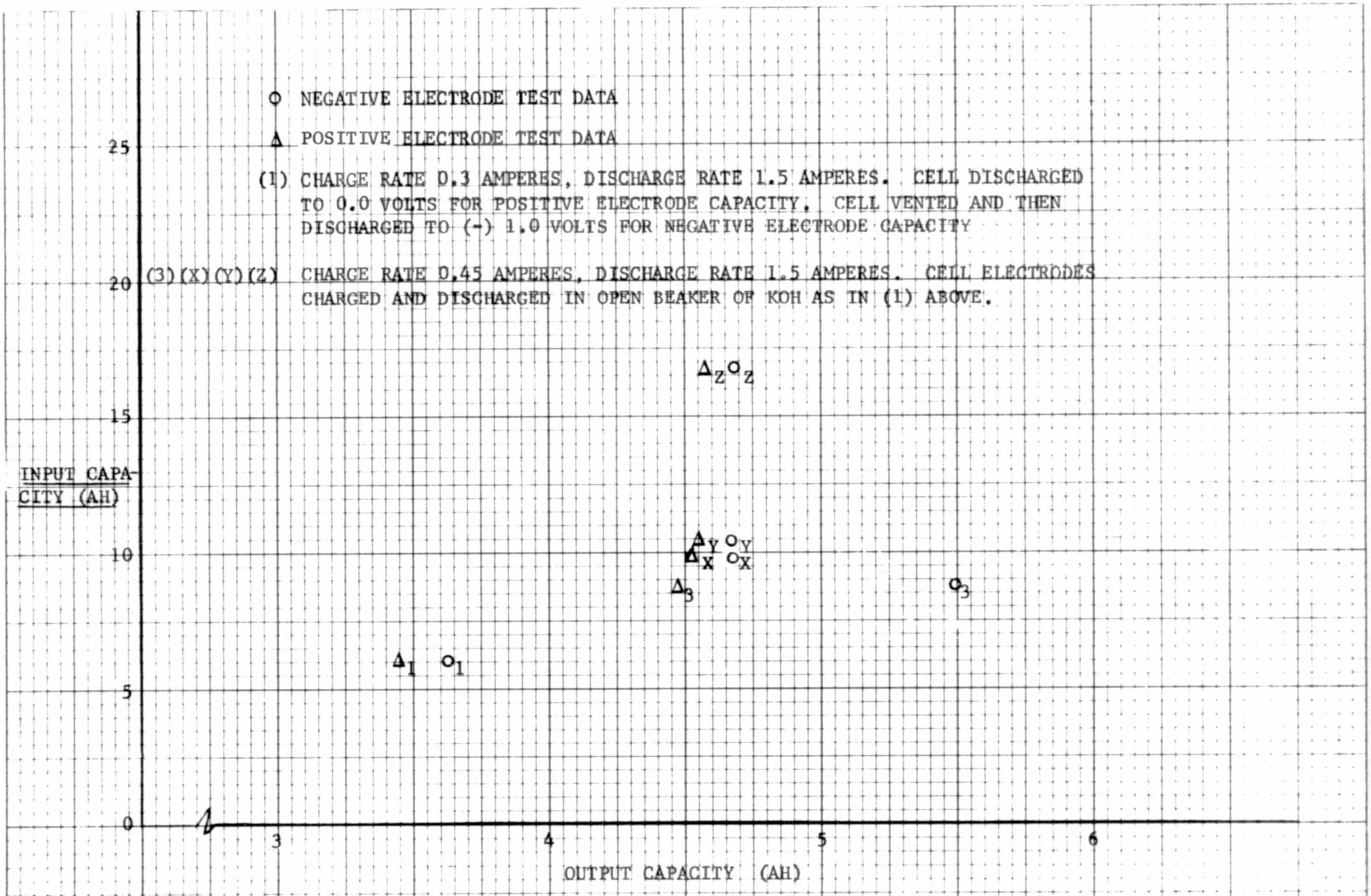


FIGURE 2. SMS BATTERY CELL S/N 296 ELECTRODE CAPACITY TEST RESULTS

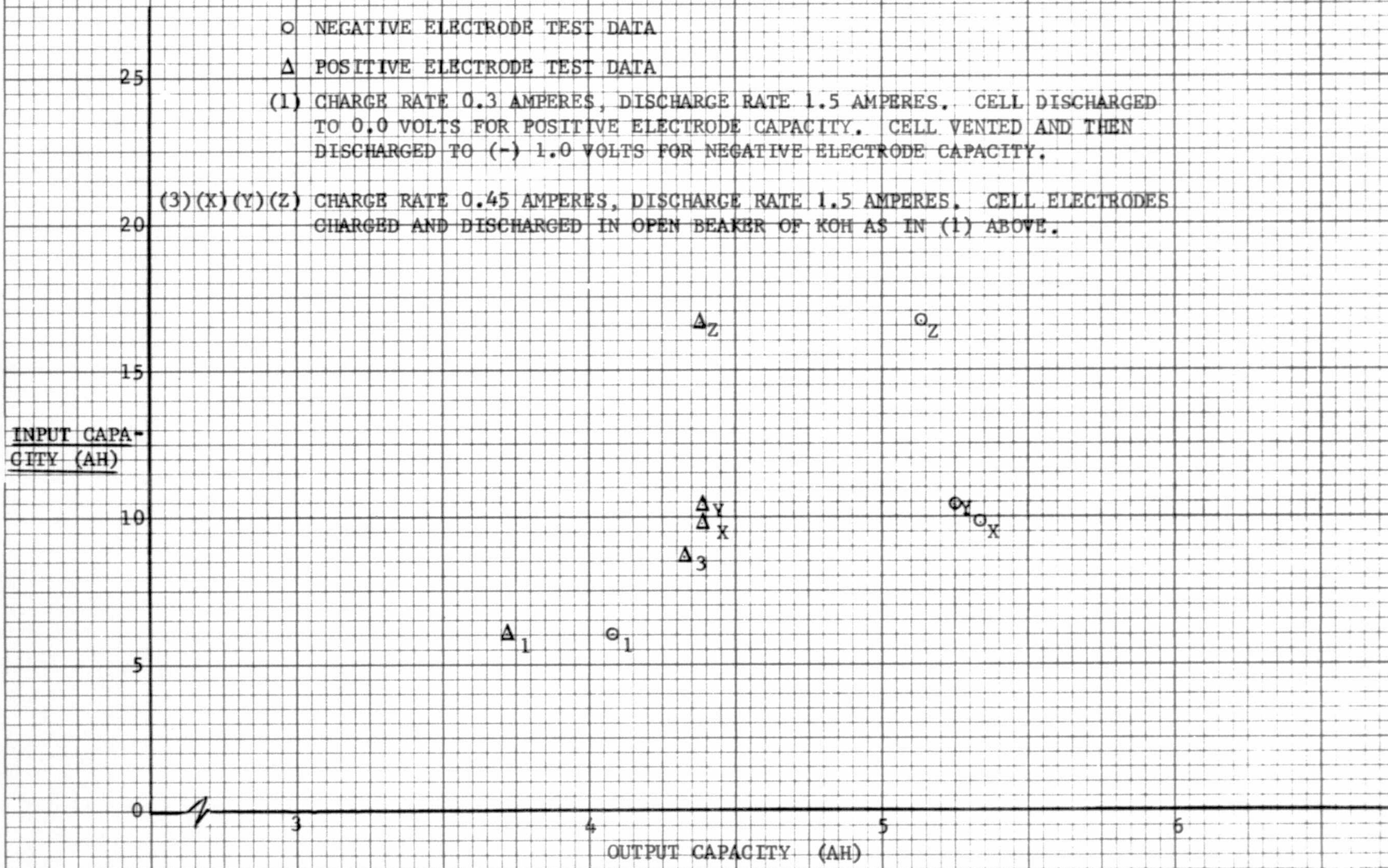
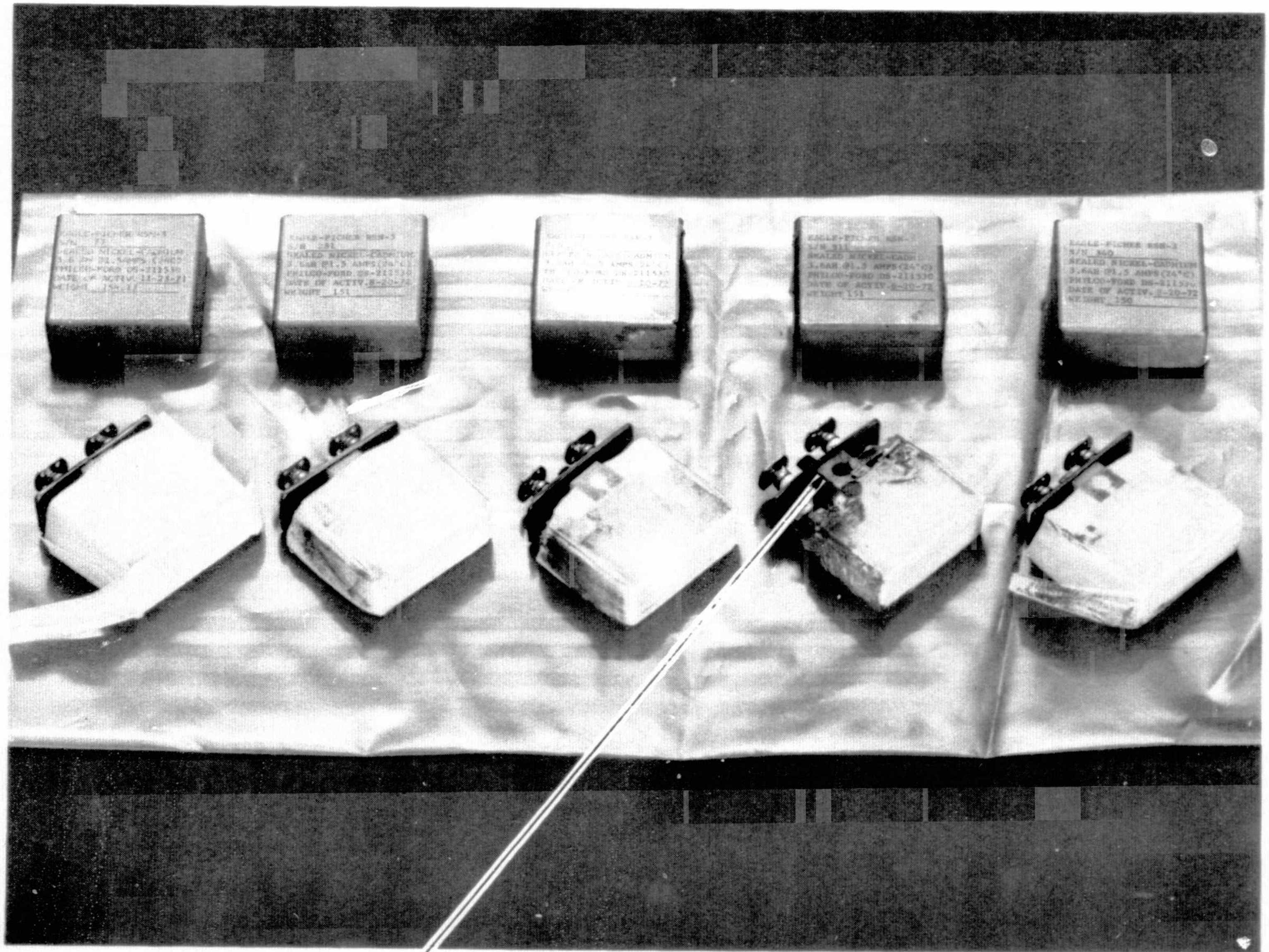


FIGURE 3. SMS BATTERY CELL S/N 311 ELECTRODE CAPACITY TEST RESULTS



(NYLON SPACER BLOCK)

FIGURE 4
DISASSEMBLED LOT 1 CELL S/N 33 and LOT 3 CELLS
S/N 281, 296, 311 and 340

APPENDIX H

EAGLE PICHER ACCEPTANCE TEST PROCEDURE ATP-279

ATP-279

ACCEPTANCE TEST PROCEDURES
FOR
RSN-3

PHILCO-FORD
SMS PROGRAM
CONTRACT NO. AT 287771 S.C.
SDRL ITEM 014

Revision C

25 September 1974

EAGLE-PICHER INDUSTRIES, INC.
ELECTRONICS DIVISION
COUPLES DEPARTMENT
JOPLIN, MISSOURI
64801

Engineering

Quality Assurance

REVISION	DATE	DESCRIPTION	APPROVAL
A	12/71	Change 40°C test temperature to 35°C. Add electrode capacity test, radiographic and electro-etching requirements.	JL
B	12/72	Revised per EO#27703	
C	9/74	Revised per EO # 28971	LSK

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1.0 SCOPE

This procedure describes the acceptance tests to be performed on Eagle-Picher P/N RSN-3. Tests will be performed in the order listed prior to delivery of the units.

2.0 REFERENCE DOCUMENTS

Eagle-Picher

005318	RSN-3 Cell Outline
EP-MP-160	Cell Conditioning Procedure
EP-MP-159	Electro-Etching Procedure
EP-MP-158	Liquid Honing Procedures
EP-MP-164	Leak Check Procedure
EP-QC-840	Radiographic Procedures
EP-WS-10	RSN-3 Welding Specification
EP-QC-839	Electrode Capacity Test Procedure
DVTP-159	Development Test Plan

Philco-Ford

SP-212064	Nickel-Cadmium Battery Cell (3.0 ampere-hour)
DS-211530	Nickel-Cadmium Battery Cell Interface Control Drawing

3.0 TEST CONDITIONS

3.1 Unless otherwise specified, laboratory ambient conditions shall be:

a) Temperature 70 ± 10° F

b) Barometric Pressure 30 ± 2" of Mercury

c) Relative Humidity Less than 90%

NOTE: Temperature control shall be maintained by locating cells in a temperature-controlled chamber with circulating air.

3.2 Tolerances

3.2.1 Temperature ± 5° F (unless otherwise specified)

3.2.2 Test Apparatus ± 2%

3.2.3 Tolerances on rates, specified test temperature, etc. are specified on individual tests in following paragraphs.

3.3 Equivalence

For purpose of this document, equivalence shall be taken to mean the ability to duplicate the function of listed equipment, including meeting specified accuracy where applicable. Listed test equipment is for reference only.

3.4 Data to be Recorded

Readings shall include cell voltage, current, pressures or transducer resistance values as applicable and temperature of at least one (1) cell in each group of 10. Frequency of readings shall be as indicated on the RSN-3 data sheets (See EP-MP-160).

3.5 General Operating Requirements

See Section 3.5 of DVTP-159.

4.0 TESTS

4.1 Test Sequence

24 Hour Vacuum Leak Test

Overcharge-Capacity 24°C (24 hour charge)

Perform 35°C Capacity

Perform 0°C Capacity

Perform 24°C Capacity

Electrolyte Leakage Test

Charge Retention Test

24 Hour Vacuum Leak Check

Tear down test set-up and disconnect leads

Pinch/weld fill tubes
Helium Leak Test
Liquid hone

Label

Electrolyte Leakage (48 hours upside down)

Final Inspection

4.4 Overcharge - 24°C Capacity Test

4.4.1 Requirement

Delivered capacity shall be 3.6 ampere-hours minimum to 1.00 volt per cell. Maximum on-charge voltage shall not exceed 1.475 volts. Cell pressure shall not exceed 75 psig.

4.4.2 Equipment

ITEM	MFR.	MODEL	ACCURACY
Power Supply	Harrison	6438 or Equivalent	N/A
Ammeters	Weston	931	± 0.5%
DVM	Cubic or Equiv.	V-71	± 0.5%
Potentiometer Pyrometer	Minimite or Equiv.		± 0.5%
Variable Resistance			N/A
Temperature Chamber	Missimers or Equiv.		

4.4.3 Procedure

4.4.3.1 Stabilize cells at 75 ± 4°F for 2 hours minimum and maintain this temperature during charge and discharge. Maintain cell temperature 75 ± 5°F. 25% of individual cells may be 75 ± 6°F. Cells are stabilized when two consecutive 15 minute readings are the same.

4.4.3.2 Charge cells at 0.3 ± .01 ampere for 24 ± 0.5 hours.

4.4.3.3 Place on open circuit for $1^{+1}_{-.5}$ hour.

4.4.3.4 Discharge at 1.5 ± .05 amperes to 1.00 volt.

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4.5 Capacity Discharge Test - 35°C (95°F)

4.5.1 Requirement

Delivered capacity shall be 2.0 ampere-hours minimum to 1.00 volt per cell. Maximum on-charge voltage shall not exceed 1.415 volts. Cell pressure shall not exceed 80 psig.

4.5.2 Equipment

(See Par. 4.3.2)

4.5.3 Procedure

4.5.3.1 Stabilize cells at 95° ± 5° for 2 hours minimum and maintain this temperature during charge and discharge. 25% of individual cells may be 95 ± 6°F. Cells are stabilized when two consecutive 15 minute readings are the same.

4.5.3.2 Charge cells at 0.3 ± .01 ampere for 20 ± 0.5 hours.

4.5.3.3 Place on open circuit for $1 {}^{+1}_{-.5}$ hour.

4.5.3.4 Discharge at 1.5 ± .05 amperes to 1.00 volt.

4.6 Capacity Discharge Test - 0°C (32°F)

4.6.1 Requirement

Delivered capacity shall be 3.0 ampere-hours minimum to 1.00 volt per cell. Maximum on-charge voltage shall not exceed 1.525 volts. Cell pressure shall not exceed 75 psig.

4.6.2 Equipment

(See Par. 4.3.2)

4.6.3 Procedure

4.6.3.1 Stabilize cells at 35 ± 2°C for a two hour minimum and maintain this temperature during charge and discharge. 25% of individual cells

4.6.3.1 Continued

may be 32 ± 6°F. Cells are stabilized when two consecutive 15 minute readings are the same.

4.6.3.2 Charge cells at 0.15 ± .01 ampere for 48 ± 0.5 hours.

4.6.3.3 Place on open circuit for $1^{+1}_{-.5}$ hour.

4.6.3.4 Discharge at 1.5 ± .05 amperes to 1.00 volt.

4.7 Capacity Discharge Test - 24°C (75°F)

4.7.1 Requirement

Delivered capacity shall be 3.6 ampere-hours minimum to 1.00 volt per cell. Maximum on-charge voltage shall not exceed 1.475 volts. Cell pressure shall not exceed 75 psig.

4.7.2 Equipment

(See Par. 4.3.2)

4.7.3 Procedure

4.7.3.1 Stabilize cells at 75 ± 5°F for a two hour minimum and maintain this temperature during charge and discharge. 25% of individual cells may be 75° ± 6°F. Cells are stabilized when two consecutive 15 minute readings are the same.

4.7.3.2 Charge cells at 0.3 ± .01 ampere for 20 ± 0.5 hours.

4.7.3.3 Place on open circuit for $1^{+1}_{-.5}$ hour.

4.7.3.4 Discharge at 1.5 ± .05 amperes to 1.00 volt.

4.2 Cell Conditioning

The cells shall have satisfactorily met the requirements of EP-MP-160 as follows:

100% Helium Leak Check gauge assemblies and cells per para. 3.2.1.

Install leads per para. 3.2.2.

Weigh cells per para. 3.2.3.

Activate and install gauges (w/venting provisions) per para. 3.2.4.

Weigh cells per para. 3.2.5.

24 Hour Vacuum Leak Test per para. 3.2.6.

Electrolyte Leak Test per para. 3.2.7.

Set up test equipment per para 3.2.8.

Perform vented cycles per para. 3.2.10 - 3.2.14.

Electrode Capacity Test per para. 3.2.15

Perform power discharge per para. 3.2.16.

Electrode Capacity Test per para. 3.2.18.

Review data of EP-MP-160 to verify compliance.

4.3 24 Hour Vacuum Leak Test

4.3.1 Requirement

There shall be no more than two (2) inches of H_g change in gauge reading after 24 hours stand.

4.3.2 Equipment

Vacuum Pump

4.3.3 Procedure

Open valves on gauges. Pull vacuum to 30". Close valve. Read/record gauge pressures. Allow 24 hour stand. Read/record gauge pressures.

4.8 Electrolyte Leakage Test

Perform Electrolyte Leakage Test per EP-MP-164, paragraph 7.0.

4.9 Charge Retention Test

4.9.1 Requirement

The cells shall have a voltage greater than 1.16 volts after 48 hour stand at 75°F.

4.9.2 Equipment

See paragraph 4.4.2.

4.9.3 Procedure

4.9.3.1 Maintain the cell temperature at 75 ± 5°F.

4.9.3.2 Connect cells with one (1) ohm resistors for $16 \begin{smallmatrix}+1 \\ -0\end{smallmatrix}$ hours.

4.9.3.3 Let cells stand on open circuit for 24 ± 0.5 hours at 75 ± 5°F. The cell voltage at the end of this open circuit stand shall be 1.16 volts or higher.

4.10 24 Hour Vacuum Leak Check

(See paragraph 4.3)

4.11 Helium Leak Test

Perform Helium Leak Test per EP-MP-164.

4.12 Final Inspection

4.12.1 Equipment

Vernier Calipers

Toledo Scales

4.12.2 Procedure

Verify cells have completed para. 4.6 thr' 7.4 of Flow Sheet. Verify conformance to Outline Drawing 005318. Refer to DS-211530 for Philco-Ford maximum outline. Record data on RSN-3 data sheet.

APPENDIX I

SMS BATTERY CELL SCREENING PROCEDURE SC-213728

PHILCO Ford

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303
FMC 11530

PROCEDURE NO.

SC-213728B

SMS

BATTERY CELL

SCREENING PROCEDURE

NOTE: All data sheet revised.

TEST START TIME/DATE ____ TEST COMPLETE TIME/DATE ____

PROGRAM SMS	PRIME CONTRACT NUMBER NAS 5-21575
Spec. Engr. ~~Date~~	R. Anderson 11/15/73
Design Engr Date 11/15/73	
Quality Assurance 11-15-73	
Test Engr 11/16/73	
	Release Date ENGR DATA NOV 21 1973 Page 1 of 188

WDL 572A (1-72)

PHILCO
WDL Division
Philco Ford Corporation
Palo Alto California 94303

TABLE OF CONTENTS

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1. SCOPE

This procedure establishes the electrical performance requirements for the screening testing of the sealed nickel-cadmium battery cells for use on the Synchronous Meteorological Satellite (SMS) program. All cells to become components of the SMS battery assemblies shall be subjected to the tests described herein and shall meet the performance criteria set forth in Table 3-2 of the Philco-Ford Power Subsystem Test Plan Specification SA-212067.

2. APPLICABLE DOCUMENTS

2.1 The following documents of the exact issue shown constitute a part of this procedure to the extent specified herein. Should a conflict exist, this procedure shall govern.

DOCUMENTS

NASA

NHB-5300.4(1B)	Quality Program for Space System Contractors

Military

MIL-STD-454	Standard General Requirements for Electronic Equipment

2.2 The following documents of the latest applicable issue form a part of this procedure to the extent referenced herein.

DRAWINGS

Philco-Ford

211530	Battery Cell Specification Control Drawing

2.2 APPLICABLE DOCUMENTS (Continued)

PLANS

<u>Philco-Ford</u>

TR 4487	SMS Quality Assurance Program Plan
SA-212067	SMS Power Subsystem Test Plan

SPECIFICATIONS

<u>Philco-Ford</u>

SD-212061B	SMS Power Control Unit, Design Specification
SP-212064C	SMS Nickel-Cadmium Battery Cell (3.0 Ampere Hour) Procurement Specification

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3. REQUIREMENTS

3.1 Design Description.- The battery cell shall be a 3 ampere-hour nickel cadmium cell, Philco-Ford part number 211530-01.

The cell shall be a component of the battery assembly, Philco-Ford part number 213827-01 which shall supply energy for the SMS mission power profile including prelaunch, hold, abort, launch/ascent, solar eclipse and peak non-eclipse operations. The role of the battery in the electrical power subsystem is defined in the SMS Power Control Unit Design Specification SD-212061.

3.1.1 Weight.- The weight of each cell shall not exceed 162 gms as specified in SP-212064.

3.1.2 Electrolyte Leakage.- The battery cell shall show no signs of electrolyte leakage when subjected to the conditions specified herein.

3.1.3 Corrosion Resistance.- All external surfaces of the battery cell shall show no evidence of corrosion when exposed to the environmental conditions specified herein.

3.1.4 Interchangeability.- All battery cells designated as Philco-Ford part number 211530-01, shall be functionally and dimensionally interchangeable in accordance with Philco-Ford Drawing 211530.

3.1.5 Marking.- Each battery cell assembly shall have a nameplate identification and serial number in accordance with Philco-Ford Drawing Drawing 211530.

3.1.6 Workmanship.- Standards of workmanship shall meet or exceed MIL-STD-454, Requirement 9. Materials utilized in the battery cell assembly shall comply with these standards.

3.1.7 Construction.- The battery cell assembly shall be constructed in accordance with the requirements of Specification SP-212064.

3.2 Battery Cell Performance.-

3.2.1 Capacity.- The Battery Cell shall meet the following capacity performance requirements, as shown in Table I.

TABLE I

SMS BATTERY ASSEMBLY CAPACITY PERFORMANCE REQUIREMENTS

Temp. (°C)	Discharge Current (Amps)	Discharge Time (Hrs)	Min. Voltage (Volts)	Min. Req'd % Rated Cap. 100%=3. (Amp Hrs)
20 ± 3	1.5	2.0	0.70	100%
2^{+4}_{-2}	1.5	1.5	0.70	75%
33^{+2}_{-4}	1.5	1.0	0.70	50%
5 to 30	1.5	1.7	0.70	85%

3.2.2 Charging.- The battery cell shall be capable of being charged at a maximum charge rate of 0.3 amperes. The maximum charging voltage shall be limited to 1.43 volts at a test temperature of 33°C, 1.52 volts at a test temperature of 20°C and 1.55 volts at a test temperature of 2°C. The battery shall be capable of accepting continuous overcharge currents of 0.3 amperes at 33°C and 20°C and 0.15 amperes at 2°C.

3.2.3 Retention of Charge.- Each cell shall be free of short circuiting paths between negative and positive terminals and shall maintain an open circuit voltage of no less than 1.16 volts when tested in accordance with 4.5.2.3. The cell shall meet the provisions of this paragraph when charged and discharged at the rates and periods specified in Paragraphs 3.2.1 and 3.2.2.

3.2.4 Reconditioning.- The battery cell shall be capable of delivering the required capacity specified in Table I after being subjected to a reconditioning procedure. Reconditioning of the battery may be required depending upon the battery use history and shall be initiated only upon notification and approval of the responsible engineer.

3.2.5 Damage Inspection.- The Battery Cell Assembly shall be capable of withstanding the environmental testing specified herein without evidence of physical damage. Damage of the assembly shall be considered to be any changes in the assembly structure or components that indicate a possible catastrophic failure is imminent.

3.2.6 Pulse Load.- The minimum allowable battery cell discharge voltage for the following pulse load conditions shall exceed 0.700 volts. The battery cell shall be initially fully charged and at a temperature of 24 ± 5°C. It shall then be subjected to a pulse load of 25.0 amperes for a period of 10 seconds followed by a load of 10.0 amperes for 5 minutes. The time interval between the first and second pulse shall be 1.0 minute.

3.3 Test Preparation.-

3.3.1 Test Apparatus.- All meters, scales, thermometers, and other test equipment used in conducting tests specified herein shall be accurate within 1% of the full scale value. Full scale deflections of meters should be not more than twice the maximum value of the quantity being measured. Periods of charge and discharge shall be timed with a device accurate to within 1.0%. All test apparatus shall be calibrated at suitable intervals against standards whose calibration is traceable to the National Bureau of Standards or equivalent. Records of such calibrations shall be available for inspection.

3.3.2 Records.- Records shall be kept and made available for inspection of the tests and of applicable manufacturing data. All test parameters shall be recorded on a continuous basis (i.e., temperature, current, voltage).

3.3.3 Test Conditions.- Unless otherwise stated, laboratory ambient conditions of tests shall be:

a. Temperature 24 ± 5°C

b. Barometric Pressure 30 ± 2 inches of mercury.

c. Relative humidity less than 90%

3.3.4 Tolerances.- Unless specifically stated in the test procedure the following test tolerances are allowable:

a.	Temperature	± 5°C
b.	Voltage	±0.5%
c.	Current	±5%
d.	Time	±10%
e.	Resistance	±5%

4. QUALITY ASSURANCE PROVISIONS

4.1 General.- This section covers Quality Assurance requirements that shall be implemented during qualification test phase to assure timely implementation of adequate controls in accordance with NHB 5300.4 (1B) and the Philco-Ford approved Quality Assurance Plan WDL TR-4487 to ensure that materials, workmanship and performance are to specified standards; and battery cells have been tested to approved specifications.

4.2 Screening Tests.- Screening tests are those tests conducted for the purpose of providing data to be used in the evaluation of the SMS battery cells. The Screening tests shall be conducted in the sequence shown in the test matrix Table II. Tests shall include, but not necessarily be limited to, those shown on the test matrix.

4.3 Inspection.-

4.3.1 Battery Cell Assembly.- The assembly shall be visually inspected for damage prior to and upon completion of each test. TFR/RMR procedures apply to all "unusual occurrences".

4.3.2 Notification.- The cognizant QA representative shall be notified at least 48 hours prior to the planned starting time of the test, so that timely notification of the customer representative can be provided.

4.3.3 Documentation.- Prior to the start of the test, the unit to be tested and the necessary documentation shall be submitted to the QA representative for review to verify test readiness. The documentation shall include at least the following:

4.3.3.1 A log for each battery cell shall be included. Each log shall be identifiable to the pertinent equipment and shall be maintained in chronological order to account for all fabrication, assembly, test and inspection operations; as well as idle periods (storage) and movements of the item. Entries shall be complete, self-explanatory and signed, and should include or refer to details such as the following:

a. Configuration data: parts list, drawings, specifications, changes, serial numbers, lot numbers.

b. Fabrication and assembly history: copies of build-up and disassembly instructions, repairs, rework, modifications.

TABLE II

BATTERY CELL
SCREENING
TEST MATRIX

PARA. REF.	TEST	Identification (3.1.5)	Dimension (3.1.0)	Weight (3.1.1)	Interchangeability (3.1.4)	Construction (3.1.7)	Workmanship (3.1.6)	Electrolyte Leakage (3.1.2)	Recondition (3.2.4)	Charge Retention (3.2.3)	Capacity (3.2.1)	Low Temp Capacity (3.2.1)	High Temp. Capacity (3.2.1)	Capacity Cycle (3.2.1)	Pulse Load (3.2.6)	Electrolyte Leakage (3.1.2)
4.5.1	Examination of Product	X	X	X	X	X	X									
4.5.2.1	Leakage							X								
4.5.2	Functional								X	X	X	X	X	X	X	
4.5.2.9	Leakage															X

4.3.3.1 Documentation.- (Continued)

c. Test and inspection records: copies of specifications, procedures, results, variables data.

d. Non-conformances summary: non-conformance list, MRB actions, failures, failure analyses, corrective actions.

e. Cumulative operating times or charge/discharge cycles.

4.3.3.2 The Battery cell drawing, shop order, etc.

4.3.4 Test Equipment Verification.- The QA representative shall verify that all test equipment to be used during the test carries evidence of valid calibration which will not expire during the expected duration of the test. Special bench test equipment (BTE) shall be accompanied by evidence that validation testing has been satisfactorily completed within the specified time period. Test equipment is listed in Table III, and the test set-up is shown in Figure 1.

4.3.5 Test Surveillance.- Before the start of testing, the QA representative will verify the test set-up. During the test, the QA representative will witness the test. He will also perform inspection of the unit under test as required by this Procedure. As a minimum, he shall indicate completion of each test sequence where surveillance is required and each test data page where witnessing is required by QA stamp.

4.4 Failure.- The term failure, as used herein, shall be defined as any occurrence which results in the inability of the test article to meet the specified performance requirements.

4.4.1 Adjustment and Repair During Tests.- No adjustments, repairs or maintenance of the test article shall be allowed except as specified herein, or as directed by the Material Review Board.

4.4.2 Test Failures.- If failure occurs during the performance of a test, the procedure described below shall be followed:

a. Quality Assurance will ensure that the failure is documented on a Request for Material Review/Trouble-Failure Report (RMR/TFR) and the cognizant Quality Engineer notified.

TABLE III

BATTERY CELL TEST EQUIPMENT LIST

Equipment	Model or Part No.*
1. Section A control	SMS BTE - #71-12-868-4A (PHOTO)
2. Section A access	SMS BTE - #71-12-868-4B (PHOTO)
3. Power source A	H/P 6271B, 6274B
4. Digital monitor	H/P 562A
5. Digital voltmeter	H/P 3440A
6. Temperature Recorder	YSI 80A with Jcn No. YSI 8423-33

*Note: Equivalent instruments may be substituted for the models listed.

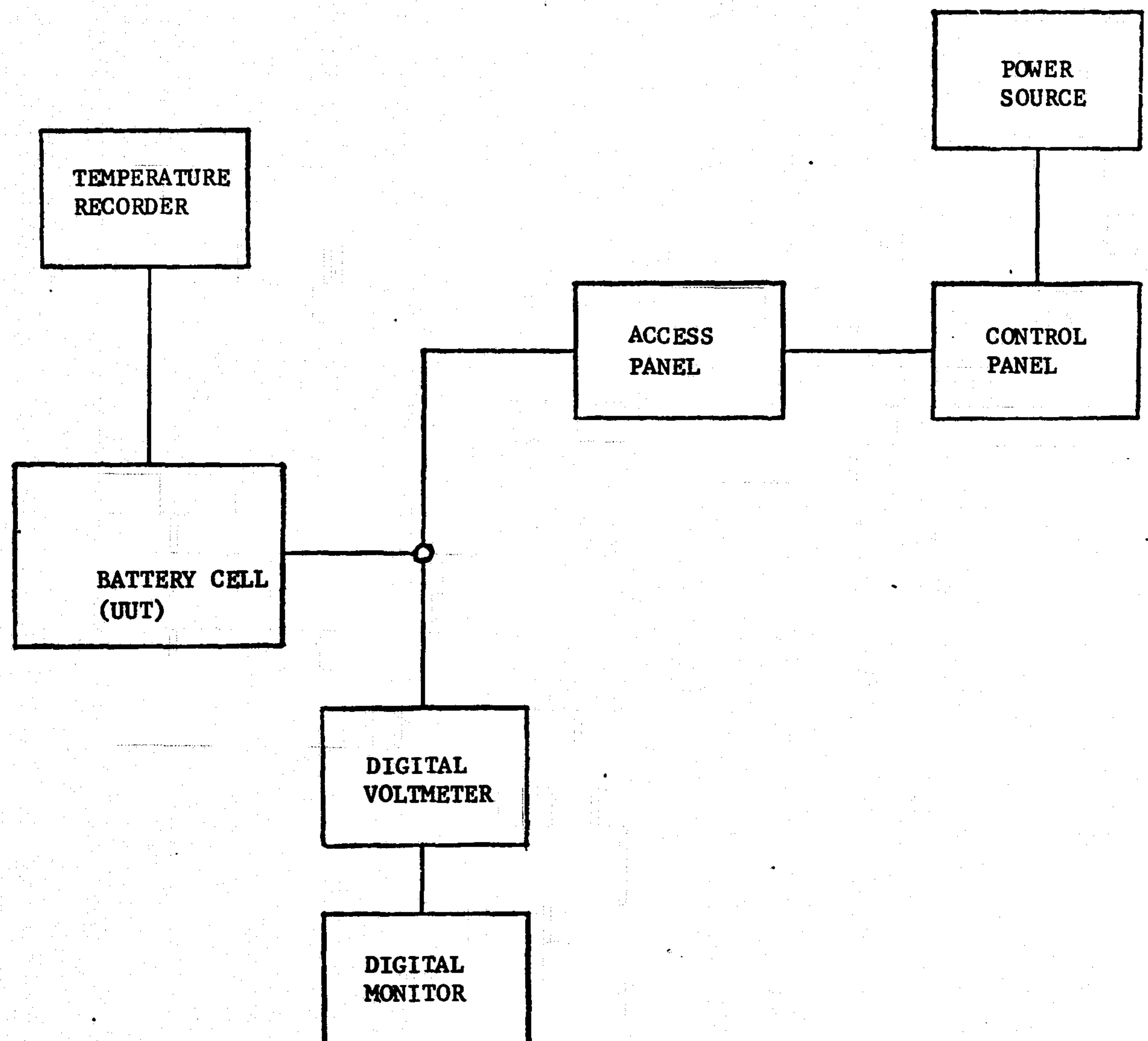

FIGURE 1. BATTERY CELL BTE BLOCK DIAGRAM

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4.4.2 Test Failures.- (Continued)

b. The QA and Engineering member of the MRB will review the RMR/TFR and determine whether to continue test, trouble-shoot to locate the probable cause, or to route the assembly being tested to rework or to the Material Review Board. The agreed upon disposition shall be entered on the RMR/TFR. In the event they are unable to reach an agreement, the assembly shall be routed to MRB.

c. When trouble-shooting is authorized and the probable cause determined, it will be documented on the RMR/TFR with a recommended course of action mutually agreed on by the QA and Engineering member of the MRB.

d. The cognizant Quality Engineer shall ensure that each test failure is reported to GSFC within 24 hours after discovery on NASA/GSFC Form 4-2 (9/67).

e. When test equipment fails during performance of the test, the measurements in progress at time of failure shall be repeated unless otherwise authorized by the QA and Engineering member of the MRB.

4.5 Test Methods.-

4.5.1 Examination of Product.- Each battery cell submitted for screening, shall be inspected to determine compliance with this procedure and drawing 211530 with respect to workmanship, construction, interchangeability, sealing, cell container, weight, dimensions, identification marking, packaging and packing, and terminals.

4.5.2 Functional Performance.-

4.5.2.1 Electrolyte Leakage.- This test shall occur immediately after completion of charge, during which cell must have received a minimum of 4 hours of overcharge to assure a positive cell pressure with respect to atmospheric pressure. An initial leakage check shall be performed to verify the integrity of the cell seals prior to electrical performance testing.

Prior to start of charge, the cell shall be thoroughly cleaned with distilled water and alcohol. All mechanically sealed areas on the cell cover shall be swabbed with phenolphthalein solution. A red

4.5.2.1 Electrolyte Leakage.- (Continued)

indication on the swab is evidence of electrolyte leakage. In the event of a positive indication, the cell shall again be cleaned and the test repeated. If a positive indication of leakage is present during the second leakage test, the cell shall be rejected. See data sheets in Appendix A for detail test steps.

4.5.2.2 Reconditioning Procedure.- Discharge the battery cells to 0.7 ± 0.30 volts at the C/2 rate (1.5 ± 0.05 amp). Then short each cell with 1 ohm until the voltage is less than 0.2 volts, but for 4 hours minimum in any case. Recharge the battery cells for 40 ± 0.5 hours at the C/20 rate (0.15 ± 0.015 amps). After charging, discharge the battery cells to 0.7 volts ± 0.30V at the C/2 rate, then place a one ohm resistor across the cell terminals until the voltage is less than 0.2 volts, but for 4 hours minimum in any case. Charge the battery cells at 0.3 ± 0.015 amperes for 16 ± 0.5 hours. Discharge the battery cells to 0.7V ± 0.3V at (1.5 ± 0.05 amps). Short each cell with a one ohm resistor for 16 ± 0.5 hours.

NOTE: Measurement accuracy shall be as specified in Paragraph 3.3.4.

4.5.2.3 Charge Retention.- This test shall be initiated with the battery cells discharged. Each cell shall be drained with a 1 ohm load for 16 ± 0.5 hours at a temperature of 20 ± 3°C. (Charge cycle #2 and discharge cycle #3 of Paragraph 4.5.2.2 may be substituted for charge/discharge cycle requirements specified in Paragraph 3.2.3 for this test.) The cell shall then be placed on open circuit for a period of 24 ± 0.5 hours at 20 ± 2°C. The cell voltage at the end of this open circuit stand period shall be 1.16 volts minimum. The measurement accuracy of the test parameters shall be in accordance with Paragraph 3.3.4. **Disconnect cells from all instrumentation and equipment for monitoring cell voltages during the 24 hour open circuit stand period.**

4.5.2.4 Capacity.- Unless otherwise specified, the capacity test shall be performed at 20° ± 3°C ambient temperature. Ampere hour capacity shall be measured to the cutoff voltage given for the rate specified and shall not be less than the capability specified in 3.2.1. Discharge each battery cell to 0.7 ± 0.3 volts, and place a 1.0 ohm resistive load on each cell until the voltage is less than 0.2 volts, but for 4 hours minimum in any case. Each battery cell shall be charged at C/10 (0.30 ± 0.015 ampere for 20 ± .5 hours then placed on a 1.0 ± 0.1 hour open circuit stand. The discharge capacity shall be at least 3.0 ampere hours at C/2 (1.5 ± .05 amperes) rate to the specified cutoff voltage. At no time shall the discharge voltage fall below 0.4 volts.

NOTES 1. The voltage on charge shall never exceed the specified maximum cell voltage of 1.52 volts.

2. Charge retention test of Paragraph 4.5.2.3 may be substituted for preliminary discharge cycle for this test.

4.5.2.4 Capacity.- (Continued)

NOTES: 3. Each cell voltage and the cell case temperature for one out of every eight cells shall be monitored continuously and recorded as follows:

a. Immediately prior and after start of each charge or discharge step.

b. At one hour maximum intervals during all charges.

c. At 15 minute maximum intervals during discharges.

4. Measurement accuracy shall be as specified in paragraph 3.3.4.

4.5.2.5 Low Temperature Capacity.- The battery cell temperature shall be maintained at 2° -2, +4°C for 6.0 ± 1.0 hours prior to and during charge and discharge. Each cell shall be fully discharged with a 1 ohm load until the voltage is less than 0.2 volts, but for 4 hours minimum in any case, then stabilized at the test temperature. (Room temperature capacity discharge cycle of Paragraph 4.5.2.4 may be substituted for preliminary discharge cycle for this test.) The battery cell charge voltage shall not exceed 1.55 volts during the 48 ± 0.5 hours charge at 0.15 ± 0.015 ampere rate. The deliverable capacity shall be at least 2.25 ampere hours at the C/2 rate (1.5 ± 0.05 amperes) when the battery cell is discharged to a voltage of 0.7 ± 0.3 volts. Measurement accuracy shall be as specified in Paragraph 3.3.4.

4.5.2.6 High Temperature Capacity.- With the battery cell temperature maintained at 33 +2, -4°C during charging and discharging, the discharge capacity shall not be less than 1.5 ampere hours when charged at C/10 (0.3 ± 0.015 ampere) for 20 ± .5 hours placed on open circuit for one hour and discharged at the two hour rate (1.5 ± 0.5 amperes) to a cell voltage of 0.7 ± 0.3 volts. Before charging the battery shall be fully discharged with a 1.0 ohm resistor placed across the cell terminals for 16.0 ± 0.5 hours and stabilized at the test temperature for 6.0 ± 0.5 hours. The maximum charge voltage shall not exceed 1.43 volts.

NOTES: 1. The measurement accuracy shall be as specified in Paragraph 3.3.4.

2. Low temperature capacity discharge cycle of Paragraph 4.5.2.5 may be substituted for preliminary discharge cycle for this test.

4.5.2.7 Capacity Cycle.- The capacity cycle test shall be performed at 20° ± 5°C temperature. Each cell shall be charged at C/10 (0.30 ± 0.015 amperes) for 20 ± .5 hours then placed on a 1.0 ± 0.1 hour open circuit stand. The cells shall then be subject to 20 discharge/charge cycles consisting of a 1.20 ± 0.1 hour at the C/2 rate 1.5 ± 0.015 amperes discharge and a 10.8 ± 0.2 hours charge at the C/10 rate 0.3 ± .003 amps. Following the 20 cycle sequence a capacity test as defined in 4.5.2.4 shall then be performed. During the 20 cycle sequence no cell voltage shall be less than 1.15 volts.

NOTE: The measurement accuracy shall be as specified in paragraph 3.3.4.

4.5.2.8 Pulse Load.- Each battery cell shall be fully charged prior to the initiation of this test. With the cell stabilized at 24 ± 5°C for 6.0 ± 0.5 hours and then discharged C/2 (1.5A ± 0.05A) for 0.2 ± 0.05 hours, each battery cell shall be subjected to two pulse load conditions as follows.

a. Discharge at 25 ± 0.5 amperes for a period of 10.0 ± 2.0 seconds.

b. Discharge at 10.0 ± 0.05 amperes for a period of 5.0 ± 0.5 minutes.

The period of time between these pulse discharge loads shall be at least 1.0 minute. The minimum allowable cell discharge voltage shall be 0.700 volt. The measurement accuracy shall meet the tolerances described in Paragraph 3.3.4.

4.5.2.9 Electrolyte Leakage.- Each battery cell shall be subject to an electrolyte leakage measurement in accordance with Paragraph 4.5.2.1. The battery cell seals shall show no evidence of electrolyte leakage.

5. PREPARATION FOR STORAGE

5.1 Preservation, Packaging and Storage.- After completion of tests each battery cell shall be preserved within two weeks by performing the following:

a. Discharge each cell below 0.1 volt by clipping a one ohm resistor across the cell terminals.

b. Remove the one ohm resistor and short the cell terminals by wrapping a copper wire around cell terminals.

c. Place each battery cell in a polyethylene bag.

d. Package each unit in a manner to avoid damage during handling.

NOTE: For long term storage (periods in excess of two weeks) battery cells shall be stored in a clean dry area at a temperature between 10 to 28°C.

6. NOTES

6.1 Definitions.-

6.1.1 Battery Cell Capacity.- Battery Cell capacity is the discharge measured quantitatively in ampere hours at the specified discharge rate to the specified cell cutoff voltage.

6.1.2 Cutoff Voltage.- The cutoff voltage of a cell is defined as that discharge voltage which represents the complete discharge condition of the cell for a particular rate. Discharge beyond this voltage would yield an insignificant amount of useful energy.

6.1.3 Reconditioning.- Depending on the use history of a Battery Cell, the responsible engineer may utilize the reconditioning procedure delineated in Paragraph 4.5.2.2 prior to any test.

7. TEST PROCEDURE DATA SUMMARY

TEST/PARAGRAPH	REQUIREMENT	DATA	DATE TEST OPERATOR QA INSPECTOR
EXAMINATION OF PRODUCT/4.5.1			
Workmanship/3.1.6	MIL-STD-454, Reqt. 9	______	______
Construction/3.1.7	SD-212066	______	______
Interchangeability/3.1.4	DWG. 213827	______	______
Weight/3.1.1	≤162 gms	______gms	______
Dimension/3.1	DWG. 211530	______	______
FUNCTIONAL PERFORMANCE/4.5.2			
Leakage/4.5.2.1	Colorless	______	______
Recondition/4.5.2.2	≥3.0 AH	______AH	______
Charge Retention/4.5.2.3	≥1.16 V/Cell	______V/Cell	______
Capacity/4.5.2.4	≥3.0 AH	______AH	______
Low Temp Capacity/4.5.2.5	≥2.25 AH	______AH	______
Hi Temp Capacity/4.5.2.6	≥1.50 AH	______AH	______
Capacity Cycle/4.5.2.7	≥3.0 AH	______AH	______
Pulse Load/4.5.2.8	≥0.7 V	______V/Cell	______
Leakage/4.5.2.9	Colorless	______	______

APPENDIX A

SMS BATTERY CELL

SCREENING PROCEDURE

DATA SHEETS

PHILCO
WDL Division
Philco-Ford Corporation
Palo Alto, California 94303

Paragraph 4.5.1

EXAMINATION OF PRODUCT TEST DATA

TEST CONDUCTOR ______________________ DATE ______________

INSPECTOR ______________________

REQUIRED: WEIGHT 162 GMS AND CHECK IF ACCEPTABLE PER SPECS.

CELL S/N	WEIGHT GMS	WORKMAN-SHIP	CONSTRUCTION	INTERCHANGE-ABILITY	DIMENSIONS	COMMENTS

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WDL-2679C (12-69)

ELECTROLYTE LEAKAGE TEST DATA

TEST CONDUCTOR ______________________ DATE ____________

INSPECTOR ______________________

REQUIRED: NO PINK OR RED COLOR

CELL S/N	CHECK IF BOTH POLES ACCEPTABLE 4.5.2.1	4.5.2.9	COMMENTS

WDL-2679C (12-69)

RECONDITIONING

4.5.2.2

CELL POSITION	CELL S/N	CELL POSITION	CELL S/N
19	____	20	____
17	____	18	____
15	____	16	____
13	____	14	____
11	____	12	____
9	____	10	____
7	____	8	____
5	____	6	____
3	____	4	____
1	____	2	____

APPENDIX J

12-CELL DEVELOPMENT TEST PROGRAM

WDL-TR-5008
19 May 1972

DEVELOPMENT REPORT FOR SYNCHRONOUS METEOROLOGICAL SATELLITE (SMS) BATTERY

FINAL REPORT

21 December 1970 to 19 May 1972

Contract No. NAS 5-21575

Prepared By: R. J. Haas,
Responsible Engineering Activity

Approved By: D. C. Briggs, Supervisor - Power Subsystem
Design and Integration Section

PHILCO-FORD CORPORATION
Western Development Laboratories
Palo Alto, California

TABLE OF CONTENTS

SMS BATTERY CELL DEVELOPMENT
PROGRAM SUMMARY

EAGLE-PICHER CELL SERIAL NUMBERS 1 THROUGH 12

DETAILED DATA SUMMARY

2-23-72 - Shorting wire removed from cells
Temperature 75°F. 0900

Reconditioning
C/10 (.3A) charge 47.5 hours. $70^{\circ} \pm 2^{\circ}$F.

2-25-72 - C/10 (.3A) charge complete 0830 $70^{\circ} \pm 2^{\circ}$F.
End of charge voltage:
(1) 1.454 (2) 1.455 (3) 1.457 (4) 1.457 (5) 1.452 (6) 1.450

(7) 1.459 (8) 1.452 (9) 1.450 (10) 1.460 (11) 1.457 (12) 1.463

C/2 (1.5A) Discharge to 1.0 V, 0905 $70^{\circ} \pm 2^{\circ}$F
Discharge Capacity (Ampere Hours):
(1) 4.50 (2) 4.59 (3) 4.50 (4) 4.50 (5) 4.50 (6) 4.50

(7) 4.55 (8) 4.50 (9) 4.59 (10) 4.50 (11) 4.50 (12) 4.50

One-ohm load on each cell 1300, 75°F.

2-28-72 - C/10 (.3A) charge 20 hours, 1315, $71^{\circ} \pm 2^{\circ}$F.

2-29-72 - C/10 (.3A) charge complete 0915 $71^{\circ} \pm 2^{\circ}$F.
End of charge voltage:
(1) 1.458 (2) 1.452 (3) 1.453 (4) 1.462 (5) 1.455 (6) 1.454

(7) 1.455 (8) 1.452 (9) 1.443 (10) 1.465 (11) 1.455 (12) 1.463

C/2 (1.5A) discharge to 1.0 V. 72°F $\pm 2^{\circ}$F, 0930
Discharge capacity (ampere hours):
(1) 4.28 (2) 4.33 (3) 4.20 (4) 4.38 (5) 4.33 (6) 4.33

(7) 4.33 (8) 4.33 (9) 4.33 (10) 4.38 (11) 4.30 (12) 4.39

C/20 charge, 1500, $28^{\circ} \pm 2^{\circ}$F, 46.7 hours.

Peak Voltage*, $28^{\circ} \pm 2^{\circ}$F, 0000 - 3/2/72
(1) 1.540 (2) 1.540 (3) 1.540 (4) 1.540 (5) 1.540 (6) 1.540

(7) 1.560 (8) 1.540 (9) 1.540 (10) 1.540 (11) 1.540 (12) 1.560

*Data reduced from multipoint chart

SMS BATTERY CELL DEVELOPMENT
PROGRAM SUMMARY

EAGLE-PICHER CELL SERIAL NUMBERS 1 THROUGH 12

DETAILED DATA SUMMARY

2-23-72 - Shorting wire removed from cells
Temperature 75°F. 0900

Reconditioning
C/10 (.3A) charge 47.5 hours. 70° ± 2°F.

2-25-72 - C/10 (.3A) charge complete 0830 70° ± 2°F.
End of charge voltage:
(1) 1.454 (2) 1.455 (3) 1.457 (4) 1.457 (5) 1.452 (6) 1.450

(7) 1.459 (8) 1.452 (9) 1.450 (10) 1.460 (11) 1.457 (12) 1.463

C/2 (1.5A) Discharge to 1.0 V, 0905 70° ± 2°F
Discharge Capacity (Ampere Hours):
(1) 4.50 (2) 4.59 (3) 4.50 (4) 4.50 (5) 4.50 (6) 4.50

(7) 4.55 (8) 4.50 (9) 4.59 (10) 4.50 (11) 4.50 (12) 4.50

One-ohm load on each cell 1300, 75°F.

2-28-72 - C/10 (.3A) charge 20 hours, 1315, 71° ± 2°F.

2-29-72 - C/10 (.3A) charge complete 0915 71° ± 2°F.
End of charge voltage:
(1) 1.458 (2) 1.452 (3) 1.453 (4) 1.462 (5) 1.455 (6) 1.454

(7) 1.455 (8) 1.452 (9) 1.443 (10) 1.465 (11) 1.455 (12) 1.463

C/2 (1.5A) discharge to 1.0 V. 72°F ± 2°F, 0930
Discharge capacity (ampere hours):
(1) 4.28 (2) 4.33 (3) 4.20 (4) 4.38 (5) 4.33 (6) 4.33

(7) 4.33 (8) 4.33 (9) 4.33 (10) 4.38 (11) 4.30 (12) 4.39

C/20 charge, 1500, 28° ± 2°F, 46.7 hours.

Peak Voltage*, 28° ± 2°F, 0000 - 3/2/72
(1) 1.540 (2) 1.540 (3) 1.540 (4) 1.540 (5) 1.540 (6) 1.540

(7) 1.560 (8) 1.540 (9) 1.540 (10) 1.540 (11) 1.540 (12) 1.560

*Data reduced from multipoint chart

3-2-72 - C/20 charge complete 1345 28 ± 2°F
End of charge voltage:
(1) 1.495 (2) 1.491 (3) 1.511 (4) 1.498 (5) 1.496 (6) 1.498

(7) 1.500 (8) 1.495 (9) 1.494 (10) 1.496 (11) 1.495 (12) 1.506

C/2 discharge to 1.0 V. 1400, 30 ± 2°F, one ohm on.
Discharge capacity (ampere hours):
(1) 3.43 (2) 3.51 (3) 3.43 (4) 3.42 (5) 3.48 (6) 3.39

(7) 3.48 (8) 3.46 (9) 3.52 (10) 3.40 (11) 3.45 (12) 3.40

3-6-72 - One-ohm off. C/10 charge, 1430, 95 ± 2°F, 23 hours.

3-7-72 - C/10 charge complete, 1310, 94 ± 3°F.
End of charge voltage:
(1) 1.384 (2) 1.385 (3) 1.388 (4) 1.384 (5) 1.383 (6) 1.385

(7) 1.385 (8) 1.384 (9) 1.382 (10) 1.393 (11) 1.387 (12) 1.392

C/2 discharge to 1.0 V. 1312, 92° - 97°F, one ohm on.
Discharge capacity (ampere hours):
(1) 2.82 (2) 2.91 (3) 2.97 (4) 2.80 (5) 2.77 (6) 2.77

(7) 2.85 (8) 2.86 (9) 2.80 (10) 3.27 (11) 2.98 (12) 3.19

3-14-72 - One-ohm off. C/10 charge, 1700, 70°F, 21.5 hours.

3-15-72 - C/10 charge complete, 1435, 70°F.
End of charge voltage:
(1) 1.490 (2) 1.492 (3) 1.494 (4) 1.497 (5) 1.499 (6) 1.498

(7) 1.502 (8) 1.493 (9) 1.495 (10) 1.495 (11) 1.487 (12) 1.499

C/2 discharge, 1.2 hour 1440, 72°F.
End of discharge voltage:
(1) 1.244 (2) 1.249 (3) 1.248 (4) 1.249 (5) --- (6) 1.250

(7) 1.251 (8) 1.248 (9) 1.248 (10) 1.250 (11) 1.248 (12) 1.246

Start C/10 charge, 10.8 hours, 1552.

3-16-72 - Cycle #2 charge, 0235
End of charge voltage:
(1) 1.463 (2) 1.465 (3) 1.468 (4) 1.466 (5) --- (6) 1.467

(7) 1.469 (8) 1.463 (9) 1.464 (10) 1.465 (11) 1.463 (12) 1.468

Cycle #2 discharge, 0350
End of discharge voltage:
(1) 1.241 (2) 1.244 (3) 1.246 (4) 1.244 (5) 1.244 (6) 1.244

(7) 1.245 (8) 1.243 (9) 1.245 (10) --- (11) 1.242 (12) 1.242

3-16-72- Cycle #3 charge, 1435, $70^{\circ}F$
End of charge voltage:
(1) 1.448 (2) 1.448 (3) 1.451 (4) 1.450 (5) 1.450 (6) 1.453
(7) 1.453 (8) 1.450 (9) 1.449 (10) 1.452 (11) 1.449 (12) 1.453

Cycle #3 discharge, 1550, $70^{\circ}F$.
End of discharge voltage:
(1) 1.237 (2) 1.240 (3) 1.241 (4) 1.239 (5) --- (6) 1.241
(7) 1.241 (8) 1.239 (9) 1.240 (10) 1.238 (11) 1.238 (12) 1.237

3-17-72 - Cycle #4 charge, 0235
End of charge voltage:
(1) 1.429 (2) 1.430 (3) 1.435 (4) 1.432 (5) --- (6) 1.433
(7) 1.434 (8) 1.435 (9) 1.432 (10) 1.430 (11) 1.433 (12) 1.433

Cycle #4 discharge, 0350
End of discharge voltage:
(1) 1.230 (2) 1.234 (3) 1.234 (4) 1.234 (5) --- (6) 1.234
(7) 1.234 (8) 1.231 (9) 1.233 (10) --- (11) 1.232 (12) 1.232

Cycle #5 charge, 1435, $72^{\circ}F$
End of charge voltage:
(1) 1.435 (2) 1.435 (3) 1.438 (4) 1.435 (5) 1.433 (6) 1.437
(7) 1.435 (8) 1.433 (9) 1.432 (10) 1.435 (11) 1.432 (12) 1.435

3-17-72 - Cycle #5 discharge, 1550
End of discharge voltage:
(1) 1.230 (2) 1.234 (3) 1.234 (4) 1.234 (5) 1.235 (6) 1.234
(7) 1.235 (8) 1.233 (9) 1.235 (10) 1.234 (11) 1.232 (12) 1.232

3-18-72 - Cycle #6 charge, 0235
End of charge voltage:
(1) 1.425 (2) 1.426 (3) 1.429 (4) 1.429 (5) 1.426 (6) 1.428
(7) 1.427 (8) 1.427 (9) 1.425 (10) 1.423 (11) 1.424 (12) 1.426

Cycle #6 discharge, 0350
End of discharge voltage:
(1) 1.232 (2) 1.235 (3) 1.235 (4) 1.235 (5) 1.236 (6) 1.235
(7) 1.237 (8) 1.232 (9) 1.235 (10) --- (11) 1.233 (12) 1.233

3-18-72 - Cycle #7 charge, 1435
End of charge voltage:
(1) 1.424 (2) 1.425 (3) 1.427 (4) 1.424 (5) 1.424 (6) 1.423
(7) 1.426 (8) 1.424 (9) 1.423 (10) 1.421 (11) 1.420 (12) 1.421
Cycle #7 discharge, 1550
End of discharge voltage:
(1) 1.225 (2) 1.230 (3) 1.231 (4) 1.229 (5) 1.230 (6) 1.231
(7) 1.229 (8) 1.229 (9) 1.228 (10) 1.228 (11) 1.228 (12) 1.229

3-19-72 - Cycle #8 Charge, 0235 *
Cycle #8 Discharge, 0350 *
Cycle #9 Charge, 1435 *
Cycle #9 Discharge, 1550 *

3-20-72 - Cycle #10 Charge, 0235 *
Cycle #10 Discharge, 0350*

*Data not available for Cycles 8, 9, and 10 due to data acquisition system malfunction.

Cycle #11 charge, 1435, 70°F.
End of charge voltage:
(1) 1.428 (2) 1.428 (3) 1.431 (4) 1.428 (5) 1.427 (6) 1.430
(7) 1.429 (8) 1.428 (9) 1.426 (10) 1.428 (11) 1.425 (12) 1.427
Cycle #11 discharge, 1550, 70°F
End of discharge voltage:
(1) 1.221 (2) 1.225 (3) 1.224 (4) 1.224 (5) 1.223 (6) 1.225
(7) 1.227 (8) 1.222 (9) 1.225 (9) 1.225 (10) 1.222 (11) 1.222 (12) 1.222

3-21-72 - Cycle #12 charge, 0235, 60°F.
End of charge voltage:
(1) 1.445 (2) 1.443 (3) 1.446 (4) 1.444 (5) --- (6) 1.444
(7) 1.448 (8) 1.446 (9) 1.444 (10) 1.442 (11) 1.442 (12) 1.443
Cycle #12 discharge, 0350, 60°F
End of discharge voltage:
(1) 1.217 (2) 1.225 (3) 1.224 (4) 1.222 (5) --- (6) 1.223
(7) 1.224 (8) 1.226 (9) 1.222 (10) 1.223 (11) 1.222 (12) 1.221
Cycle #13 charge, 1435, 60°F
End of charge voltage:
(1) 1.448 (2) 1.445 (3) 1.448 (4) 1.444 (5) 1.446 (6) 1.450
(7) 1.447 (8) 1.446 (9) 1.443 (10) 1.446 (11) 1.443 (12) 1.446

3-21-72 - Cycle #13 discharge, 1550, 60°F
End of discharge voltage:
(1)1.221 (2)1.226 (3)1.225 (4)1.224 (5)1.224 (6)1.225
(7)1.227 (8)1.223 (9)1.226 (10)1.222 (11)1.223 (12)1.222

3-22-72 - Cycle #14 charge, 0235, 60°F
End of charge voltage:
(1)1.442 (2)1.441 (3)1.443 (4)1.439 (5)1.439 (6)1.444
(7)1.442 (8)1.440 (9)1.438 (10)--- (11)1.438 (12)1.440

Cycle #14 discharge, 0350, 60°F
End of discharge voltage:
(1)1.226 (2)1.228 (3)1.230 (4)1.228 (5)1.229 (6)1.233
(7)1.231 (8)1.230 (9)1.230 (10)1.231 (11)1.227 (12)---

Cycle #15 charge, 1435, 60°F
End of charge voltage:
(1)1.447 (2)1.444 (3)1.447 (4)1.443 (5)1.444 (6)1.447
(7)1.445 (8)1.444 (9)1.442 (10)1.444 (11)1.442 (12)1.444

Cycle #15 discharge, 1550, 60°F
End of discharge voltage:
(1)1.216 (2)1.221 (3)1.220 (4)1.219 (5)1.219 (6)1.220
(7)1.222 (8)1.218 (9)1.221 (10)1.217 (11)1.219 (12)1.218

3-23-72 - Cycle #16 charge, 0235, 60°F
End of charge voltage:
(1)1.440 (2)1.438 (3)1.442 (4)1.438 (5)1.442 (6)1.442
(7)1.441 (8)1.440 (9)1.438 (10)1.437 (11)1.439 (12)---

Cycle #16 discharge, 0350, 60°F
End of discharge voltage:
(1)--- (2)1.225 (3)1.231 (4)1.230 (5)1.229 (6)1.230
(7)1.232 (8)1.228 (9)1.230 (10)--- (11)1.227 (12)1.225

Cycle #17 charge, 1435, 60°F
End of charge voltage:
(1)1.446 (2)1.445 (3)1.447 (4)1.442 (5)1.444 (6)1.447
(7)1.446 (8)1.444 (9)1.442 (10)1.444 (11)1.442 (12)1.444

Cycle #17 discharge, 1550, 60°F
End of discharge voltage:
(1)1.218 (2)1.222 (3)1.221 (4)1.221 (5)1.220 (6)1.222
(7)1.224 (8)1.220 (9)1.222 (10)1.220 (11)1.220 (12)1.219

3-24-72 - Cycle #18 charge, 0235, 60°F
End of charge voltage:
(1) 1.440 (2) 1.440 (3) 1.442 (4) 1.438 (5) 1.440 (6) 1.442
(7) 1.440 (8) 1.439 (9) 1.437 (10) 1.437 (11) 1.439 (12) ---

Cycle #18 discharge, 0350, 60°F
End of discharge voltage:
(1) 1.225 (2) 1.226 (3) 1.227 (4) 1.231 (5) 1.231 (6) 1.229
(7) 1.230 (8) 1.231 (9) 1.227 (10) 1.229 (11) 1.227 (12) 1.226

Cycle #19 charge, 1435, 60°F
End of charge voltage: *

*Data not available due to data tape change during period of acquisition.

Cycle #19 discharge, 1550, 60°F
End of discharge voltage:
(1) 1.224 (2) 1.230 (3) 1.230 (4) 1.229 (5) 1.229 (6) 1.230
(7) 1.231 (8) 1.226 (9) 1.228 (10) 1.227 (11) 1.225 (12) 1.226

3-25-72 - Cycle #20 charge, 0235
End of charge voltage:
(1) 1.440 (2) 1.437 (3) 1.437 (4) 1.441 (5) 1.437 (6) 1.441
(7) 1.440 (8) 1.439 (9) 1.438 (10) 1.436 (11) 1.436 (12) 1.438

Cycle #20 discharge, 0350
End of discharge voltage:
(1) --- (2) 1.217 (3) 1.222 (4) 1.222 (5) 1.221 (6) 1.221
(7) 1.223 (8) 1.219 (9) 1.222 (10) --- (11) 1.218 (12) 1.218

Cycle #21 charge, 1435, 85°F
End of charge voltage:
(1) 1.440 (2) 1.438 (3) 1.441 (4) 1.438 (5) --- (6) 1.442
(7) 1.440 (8) 1.438 (9) 1.437 (10) --- (11) 1.436 (12) 1.439

3-25-72 - Cycle #21 discharge, 1550, 85°F
End of discharge voltage:
(1) --- (2) 1.231 (3) 1.236 (4) 1.236 (5) 1.236 (6) 1.235
(7) 1.236 (8) 1.232 (9) 1.233 (10) 1.234 (11) 1.232 (12) 1.231

3-26-72 - Cycle #22 charge, 0235, 85°F
End of charge voltage:
(1) 1.384 (2) 1.385 (3) 1.389 (4) 1.385 (5) --- (6) 1.386
(7) 1.390 (8) 1.388 (9) 1.386 (10) --- (11) 1.391 (12) 1.395

3-26-72 - Cycle #22 discharge, 0350, 85°F
End of discharge voltage:
(1) 1.214 (2) 1.214 (3) 1.217 (4) 1.216 (5) 1.213 (6) 1.218

(7) 1.217 (8) 1.216 (9) 1.215 (10) 1.216 (11) 1.217 (12) 1.211

Cycle #23 charge, 1435, 85°F
End of charge voltage:
(1) 1.395 (2) 1.395 (3) 1.392 (4) 1.386 (5) 1.390 (6) 1.390

(7) 1.390 (8) 1.387 (9) 1.392 (10) 1.392 (11) 1.390 (12) 1.388

Cycle #23 discharge, 1550, 85°F
End of discharge voltage:
(1) --- (2) 1.211 (3) 1.216 (4) 1.216 (5) 1.215 (6) 1.215

(7) 1.217 (8) 1.213 (9) 1.215 (10) --- (11) 1.213 (12) 1.214

3-27-72 - Cycle #24 charge, 0235, 85°F
End of charge voltage:
(1) 1.387 (2) 1.388 (3) 1.388 (4) 1.391 (5) 1.386 (6) 1.386

(7) 1.389 (8) 1.389 (9) 1.388 (10) 1.385 (11) 1.392 (12) 1.397

Cycle #24 discharge, 0350, 85°F
End of discharge voltage:

*Data not available due to data tape change during period of acquisition.

Cycle #25 charge, 1435, 85°F
End of charge voltage:
(1) 1.396 (2) 1.398 (3) 1.401 (4) 1.395 (5) 1.396 (6) 1.396

(7) 1.399 (8) 1.397 (9) 1.395 (10) 1.405 (11) 1.401 (12) 1.405

Cycle #25 discharge, 1550, 85°F
End of discharge voltage:
(1) 1.207 (2) 1.212 (3) 1.213 (4) 1.211 (5) 1.209 (6) 1.211

(7) 1.215 (8) 1.209 (9) 1.212 (10) 1.212 (11) 1.210 (12) 1.212

3-28-72 - Cycle #26 charge, 0235, 85°F
End of charge voltage:
(1) 1.389 (2) 1.392 (3) 1.396 (4) 1.390 (5) --- (6) 1.392

(7) 1.394 (8) 1.390 (9) 1.389 (10) --- (11) 1.394 (12) 1.398

Cycle #26 discharge, 0350, 85°F
End of discharge voltage:
(1) 1.206 (2) 1.212 (3) 1.212 (4) 1.212 (5) 1.209 (6) 1.210

(7) 1.214 (8) 1.206 (9) 1.209 (10) 1.208 (11) 1.207 (12) 1.208

3-28-72 - Cycle #27 charge, 1435, 85°F
End of charge voltage:
(1) 1.390 (2) 1.390 (3) 1.394 (4) 1.397 (5) 1.391 (6) 1.391
(7) 1.392 (8) 1.394 (9) 1.392 (10) 1.389 (11) 1.395 (12) 1.398

Cycle #27 discharge, 1550, 85°F
End of discharge voltage:
(1) 1.203 (2) 1.208 (3) 1.209 (4) 1.206 (5) 1.205 (6) 1.206
(7) 1.211 (8) 1.204 (9) 1.208 (10) 1.208 (11) 1.206 (12) 1.208

3-29-72 - Cycle #28 charge, 0235, 85°F
End of charge voltage:
(1) 1.388 (2) 1.391 (3) 1.395 (4) 1.390 (5) 1.391 (6) 1.394
(7) 1.393 (8) 1.390 (9) 1.389 (10) 1.394 (11) --- (12) 1.398

Cycle #28 discharge, 0350, 85°F
End of discharge voltage:
(1) --- (2) 1.205 (3) 1.211 (4) 1.213 (5) 1.208 (6) 1.208
(7) 1.213 (8) 1.206 (9) 1.209 (10) --- (11) 1.208 (12) 1.209

Cycle #29 charge, 1435, 85°F
End of charge voltage:
(1) 1.393 (2) 1.395 (3) 1.399 (4) 1.394 (5) 1.394 (6) 1.395
(7) 1.396 (8) 1.393 (9) 1.392 (10) 1.400 (11) 1.395 (12) 1.400

Cycle #29 discharge, 1550, 85°F
End of discharge voltage:
(1) 1.198 (2) 1.205 (3) 1.205 (4) 1.202 (5) 1.200 (6) 1.202
(7) 1.208 (8) 1.200 (9) 1.204 (10) 1.205 (11) 1.203 (12) 1.204

3-30-72 - Cycle #30 charge, 0235, 85°F
End of charge voltage:
(1) 1.388 (2) 1.391 (3) 1.395 (4) 1.390 (5) 1.391 (6) 1.392
(7) 1.390 (8) 1.389 (9) 1.392 (10) 1.391 (11) 1.396 (12) 1.396

Cycle #30 discharge, 0350, 85°F
End of discharge voltage:
(1) 1.204 (2) 1.210 (3) 1.212 (4) 1.208 (5) 1.208 (6) 1.206
(7) 1.207 (8) 1.206 (9) 1.212 (10) 1.205 (11) 1.208 (12) 1.206

Cycle #31 charge, 1435, 85°F
End of charge voltage:
(1) 1.385 (2) 1.388 (3) 1.391 (4) 1.388 (5) 1.389 (6) 1.389
(7) 1.392 (8) 1.390 (9) 1.389 (10) 1.394 (11) --- (12) 1.399

3-30-72 - Cycle #31 discharge, 1550, 85°F
End of discharge voltage:
(1)1.203 (2)1.204 (3)1.210 (4)1.210 (5)1.207 (6)1.206

(7)1.206 (8)1.212 (9)1.204 (10)1.207 (11)1.206 (12)1.208

3-31-72 - Cycle #32 charge, 0235, 85°F
End of charge voltage:
(1)1.384 (2)1.385 (3)1.387 (4)1.383 (5)1.383 (6)1.385

(7)1.385 (8)1.383 (9)1.383 (10)--- (11)1.387 (12)1.389

Cycle #32 discharge, 0350, 85°F
End of discharge voltage:

*Data not available due to data tape change during period of acquisition.

Cycle #33 charge, 1435, 85°F
End of charge voltage:

*Data not available due to data tape change during period of acquisition.

Cycle #33 discharge, 1550, 85°F
End of discharge voltage:
(1)1.190 (2)1.197 (3)1.198 (4)1.193 (5)1.194 (6)1.192

(7)1.199 (8)1.190 (9)1.194 (10)1.197 (11)1.194 (12)1.196

4-4-72 - C/20 charge, 0900, 70°F, 56,5 hours.

4-6-72 - Charge complete, 1730, 72°F
End of charge voltage:
(1)1.426 (2)1.426 (3)1.428 (4)1.428 (5)1.427 (6)1.430

(7)1.428 (8)1.427 (9)1.427 (10)1.424 (11)1.422 (12)1.426

4-7-72 - C/20 charge, 1025, 28 $\pm$ 2°F, 3.75 hours.
Peak charge voltages (1215, 28 $\pm$ 2°F):
(1)1.588 (2)1.595 (3)1.594 (4)1.581 (5)1.582 (6)1.593

(7)1.593 (8)1.586 (9)1.592 (10)1.577 (11)1.616 (12)1.616

End of charge voltages (1410, 28 $\pm$ 2°F):
(1)1.488 (2)1.488 (3)1.490 (4)1.487 (5)1.480 (6)1.477

(7)1.480 (8)1.479 (9)1.477 (10)1.474 (11)1.468 (12)1.473

4-7-72 - C/2 discharge to 1.0 V., 1430, 70^{o}F
Discharge capacity (ampere hours):
(1)4.45 (2)4.60 (3)4.56 (4)4.53 (5)4.51 (6)4.50

(7)4.57 (8)4.48 (9)4.60 (10)4.54 (11)4.50 (12)4.50

C/10 charge, 1740, 70^{o}F, 23 hours.

4-8-72 - Charge complete, 1650, 70^{o}F
End of charge voltage:
(1)1.443 (2)1.443 (3)1.444 (4)1.442 (5)1.439 (6)1.443

(7)1.447 (8)1.444 (9)1.441 (10)1.446 (11)1.442 (12)1.446

4-9-72 - C/2 discharge to 1.0 V., 1105, 70^{o}F
Discharge capacity (ampere hours):
(1)3.81 (2)3.93 (3)3.81 (4)3.81 (5)3.81 (6)3.81

(7)3.94 (8)3.82 (9)3.94 (10)3.82 (11)3.82 (12)3.82

C/10 charge, 1400, 70^{o}F., 19.4 hours

4-10-72 - Charge complete, 0940, 70^{o}F
End of charge voltage:
(1)1.439 (2)1.439 (3)1.439 (4)1.441 (5)1.438 (6)1.445

(7)1.443 (8)1.436 (9)1.442 (10)1.437 (11)1.433 (12)1.436

C/20 charge, 1310, 32 $\pm$ 2^{o}F, 26.5 hours

Peak charge voltages (1900, 32 $\pm$ 2^{o}F):
(1)1.519 (2)1.535 (3)1.521 (4)1.519 (5)1.512 (6)1.538

(7)1.518 (8)1.524 (9)1.524 (10)--- (11)1.551 (12)1.572

4-11-72 - Charge complete, 1545, 32 $\pm$ 2^{o}F
End of charge voltages:
(1)1.490 (2)1.487 (3)1.487 (4)1.486 (5)1.487 (6)1.500

(7)1.489 (8)1.486 (9)1.485 (10)1.483 (11)1.482 (12)1.484

4-12-72 - C/2 discharge to 1.0 V., 0900, 60^{o}F
Discharge capacity (ampere hours):
(1)3.70 (2)3.70 (3)3.72 (4)3.74 (5)3.74 (6)3.74

(7)3.90 (8)3.75 (9)3.76 (10)3.76 (11)3.78 (12)3.78

C/20 charge, 1600, 28 $\pm$ 2^{o}F, (66 hours)

4-12-72 - Peak charge voltages (1500, 28 ± 2°F):

(1) 1.540 (2) 1.542 (3) 1.538 (4) 1.541 (5) 1.542 (6) 1.554

(7) 1.516 (8) 1.549 (9) 1.539 (10) 1.534 (11) 1.535 (12) 1.582

4-15-72 - Charge complete, 1005, 28 ± 2°F
End of charge voltages:

(1) 1.495 (2) 1.490 (3) 1.490 (4) 1.490 (5) 1.493 (6) 1.494

(7) 1.508 (8) 1.493 (9) 1.492 (10) 1.493 (11) 1.494 (12) 1.501

4-24-72 - One -ohm short on 24 hour, 75°F

Charge retention voltages:

(1) 1.208 (2) 1.216 (3) 1.219 (4) 1.218 (5) 1.218 (6) 1.219

(7) 1.223 (8) 1.218 (9) 1.218 (10) 1.217 (11) 1.217 (12) 1.220

APPENDIX K

SMS BATTERY ASSEMBLY PROCEDURE SC-213772

PHILCO Ford

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303
FMC 11530

PROCEDURE NO.

SC-213772A
Amendment #1

BATTERY ASSEMBLY PROCEDURE

FOR SMS

This amendment forms a part of Procedure SC-213772A, dated May 11, 1973.

Paragraph 3.8 Final Battery Assembly, Reference Engineering Drawing 213827.- Make the changes indicated below:

Paragraph 3.8.7 Add the following:

"Prior to bonding the support blocks to the assembly, the support block surfaces shall be lightly sanded per paragraph 3.4.2 of WDL Procedure SV-225112."

VERIFIED COPY

Date Verified 12-6-74 | Procedure | Revision | Amendment 1

Verified by D. Costa

VOID After Date

PROGRAM SMS	PRIME CONTRACT NUMBER NAS5-21575
Spec. Engr. [signature] Date 9-17-73	
Resp. Engr. [signature] Date 9-17-73	
Product Assurance [signature] 9-18-73	
Test Engineering W L Twelker 9-18-73	
	Release Date ENGR DATA SEP 19 1973 Page 1 of 2

WDL—572A (1-72)

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PHILCO Ford

WDL Division
Philco-Ford Corporation
Palo Alto, California 94303
FMC 11530

PROCEDURE NO.

SC-213772A
Amendment #1

BATTERY ASSEMBLY PROCEDURE

FOR SMS

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Paragraph 3.8 Final Battery Assembly, Reference Engineering Drawing 213827.- Make the changes indicated below:

Paragraph 3.8.7 Add the following:

"Prior to bonding the support blocks to the assembly, the support block surfaces shall be lightly sanded per paragraph 3.4.2 of WDL Procedure SV-225112."

VERIFIED COPY

Date Verified	Procedure
12-6-74	Revision
Verif...	Amendment 1
D. Costa	Date
VOID After Date	

PROGRAM	SMS	PRIME CONTRACT NUMBER	NAS5-21575
Spec. Engr. [signature]	Date 9-17-73		
Resp. Engr. [signature]	Date 9-17-73		
Product Assurance [signature]	9-18-73		
Test Engineering W L Twechen	9-18-73		
		Release Date ENGR DATA SEP 19 1973	Page 1 of 2

WDL-572A (1-72)

Paragraph 3.8.13 Change the last sentence to read:

"Torque the connector screws to a value of 3.5 to 4.7 inch-pounds."

Paragraph 3.8.17 Add the following to the third sentence:

".... and base of connector screw lock assembly."

Paragraph 2.1 under INDUSTRIAL:

Add:	"SV-225112	Application of Black Thermal Control Paint Systems"

PHILCO Ford

.WDL Division
Philco-Ford Corporation
Palo Alto, California 94303

SPECIFICATION NO.

SC 213772A

TITLE

BATTERY ASSEMBLY PROCEDURE

FOR SMS

VERIFIED COPY		
Date Verified 12-6-74	Procedure	
Verified by ENG D. Costa	Revision	A
	Amendment	
QC Verification	Stamp	Date
VOID Afte. Date		

PROGRAM/SITE SMS		PRIME CONTRACT NUMBER NAS5-21575	
Spec. Engr. D K Sperling	Date 4-10-73		
Resp. Engr. [illegible]	4/10/73		
Product Assurance [illegible] FOR R. T. WHITTEMORE	4-27-73		
		Outside WDL	
		Release Date ENGR DATA MAY 11 1973	Page 1 of 11

WDL-572A (9-69)

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1.0 SCOPE

This Specification describes the procedure for the assembly of the SMS nickel-cadmium battery power supply, Philco-Ford Part No. 40-213827. The battery assembly consists of twenty individual cells, which receive a paint coating and an insulation wrap. Subsequently, the individual cells are assembled with related end plates, support ribs, wiring and connecting hardware.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents form a part of this process to the extent specified herein. Where conflicting requirements exist, this procedure shall govern.

MILITARY

NASA (Publications) NHB 5300.4 (1B)	Quality Control Provisions for Aeronautical and Space System Contractors
NASA NHB 5300.4 (3A)	Requirements for Soldered Electrical Connections

INDUSTRIAL

Philco-Ford (Standards) WDL 88-3016	Paint, Finishes, Industrial
Philco-Ford WDL 88-5011	Crimped Solderless Connections
Philco-Ford WDL 88-5519	Lacing
Philco-Ford WDL 88-6111	Torque Requirements for Threaded Devices
Philco-Ford WDL 88-7009	Marking for Identification
Philco-Ford WDL 88-7011	Safety Wiring
Philco-Ford (Specification) WDL SD-212066	Design Report for SMS Battery
Philco-Ford WDL 88-4002	Manufacturing Standard

2.1 (Cont'd)

Philco-Ford (Drawings) 211103	Battery
Philco-Ford 211530	Cell, Battery
Philco-Ford 213827	Power Supply, Battery
Philco-Ford 213828	Power Supply, Battery, Wiring Diagram
Philco-Ford 213831	Cell, Battery, Modified

3.0 REQUIREMENTS

The following materials, equipment and procedures shall be utilized to produce the battery assembly.

3.1 Base Materials.-

3.1.1 Battery Cells, Philco-Ford 211530.

3.1.2 End Plates, Magnesium, Philco-Ford 20-213829-01 and -02.

3.1.3 Support Blocks, Epoxy-Fiber Glass, Philco-Ford 21-213833-01 and 21-213834-01.

3.1.4 Cell Support Rib, Magnesium, Philco-Ford 20-213830-01.

3.1.5 Thermistors, Philco-Ford 52-P11050-0001.

3.1.6 Connector, Philco-Ford 41-P10052-0008.

3.1.7 Screw Assemblies, Philco-Ford 25-P10013-0001.

3.1.8 Bolts, Philco-Ford 25-213832-01.

3.1.9 Screw, Philco-Ford 25-P10074-0031.

3.1.10 Nuts, Philco-Ford 25-213835-01 and 25-P10067-0003.

3.1.11 Washers, Philco-Ford 25-P10044-0021, 25-P10063-0003, MS35335-58 and 25-P10044-0011.

3.1.12 Wire, Philco-Ford 03-P12104-0020 and 03-P12104-0040.

3.1.13 Safety Wire, MS 20995-AA47.

3.1.14 Lug, Wire, Philco-Ford 25-P10070-0003.

3.1.15 Tubing, Teflon, Philco-Ford 08-P12117-0023.

3.1.16 Solder SN 60, Philco-Ford 09-P12024-0003.

3.1.17 Paint, Primer, Wash, Philco-Ford 020077-0001A&B.

3.1.18 Paint, Black, Philco-Ford 11-020054-0001.

3.1.19 Adhesive, Silicone, Philco-Ford 23-P12351-0003.

3.1.20 Adhesive, Epoxy, Philco-Ford 23-P12146-0001 and 23-P12137-0001.

3.1.21 Silica, Pyrogenic, Philco-Ford 11-P12013-0001.

3.1.22 Lacing, Philco-Ford 12-020056-0001.

3.1.23 Sleeving, shrink, Philco-Ford 08-P12107-0002/A.

3.1.24 Mylar, sheet, 05-P12097-XXXX.

3.2 Support Materials.-

3.2.1 Plastic Bags, heat-sealable.

3.2.2 Mold Release, fluorocarbon type.

3.2.3 Tongue Depressors.

3.2.4 Cotton Tip Applicators.

3.2.5 Kimwipes.

3.2.6 Solvents: Alcohol; MEK; Methylene Chloride.

3.2.7 Mixing Cups, Plastic.

3.2.8 Syringes, Plastic.

3.2.9 Masking Tape, Paper.

3.2.10 Tags: String; Paper.

3.2.11 Gloves: Cotton; Nylon; Vinyl.

3.2.12 Flux, Solder, Type RA.

3.2.13 Silk Screen, Identification Label.

3.2.14 Storage Box, Battery.

3.2.15 Thermal Vacuum Grease.

3.3 <u>Equipment.-</u>

3.3.1 Spray Gun Assembly.

3.3.2 Plastic Bag Sealer.

3.3.3 Knives, No. 2, Scalpel.

3.3.4 Scissors.

3.3.5 Solvent Dispenser, Plastic.

3.3.6 Torque Wrench, 7/16 and 3/16 Inch, Hex Head, Socket.

3.3.7 Safety Wire Pliers.

3.3.8 Brushes: Paint; Acid.

3.3.9 Adjustable Vise.

3.3.10 Crimping Tool.

3.3.11 Wire Stripper.

3.3.12 Wire Heat Sinks.

3.3.13 Soldering Irons.

3.3.14 Diagonal Cutters.

3.3.15 Balance, Weight, Ohaus, 1 gm Accuracy.

3.3.16 Force Beam, Center of Mass.

3.4 Tooling and Shop Aids.-

3.4.1 Battery Assembly Alignment Fixture, Shop Aid No. 0100.

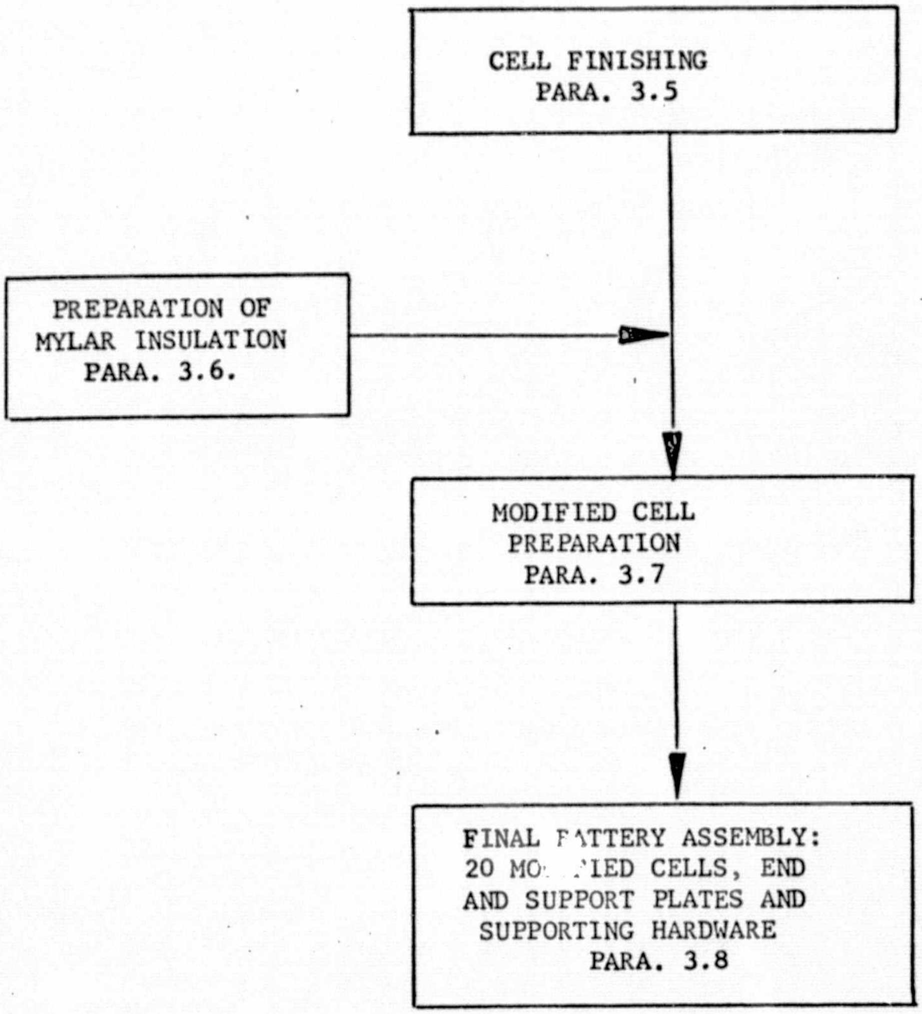
3.4.2 Battery Mounting Hole Drilling Fixture, Shop Aid No. 0101.

3.4.3 Mylar Pattern Tool, Shop Aid No. 0102.

3.4.4 Mylar Fold Tool, Shop Aid No. 0103.

3.4.5 Mylar Form Tool, Shop Aid No. 0104.

ASSEMBLY SEQUENCE



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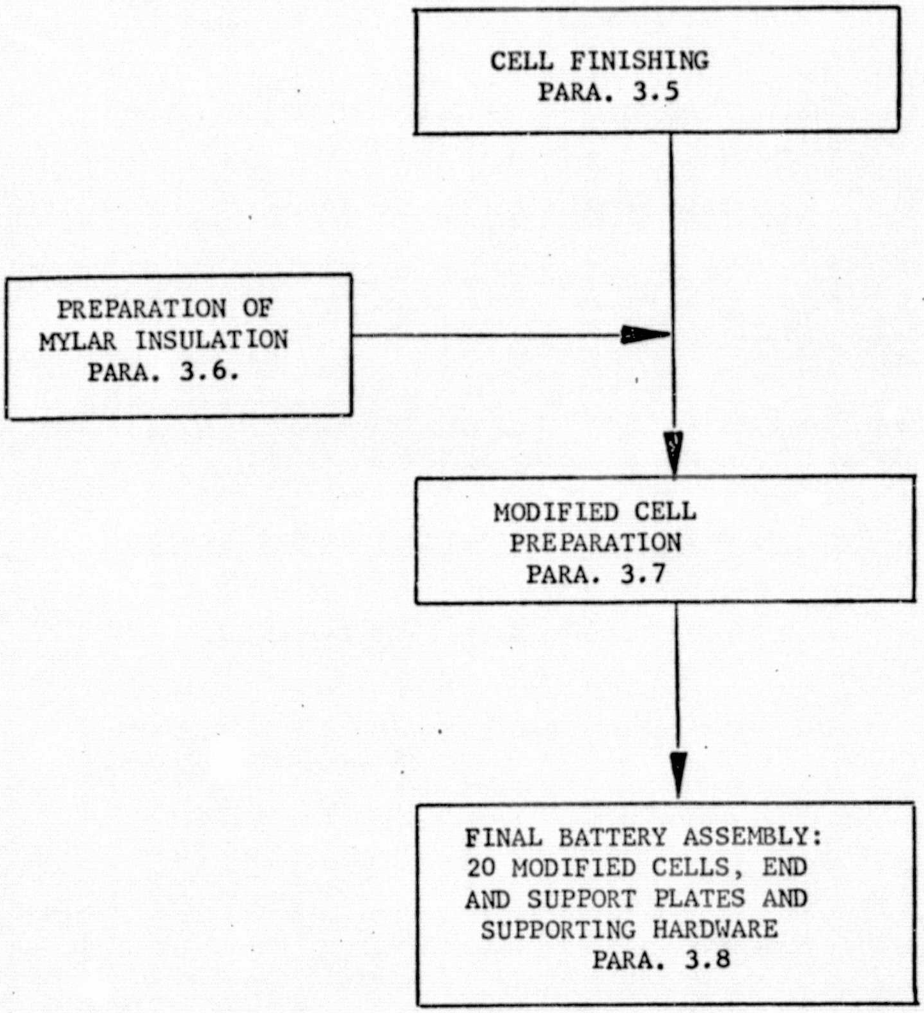

C-4

ASSEMBLY PROCESS

3.5 Cell Preparation, Reference Engineering Drawing 213831.-

3.5.1 Clean each of the twenty individual battery cells (WDL 211530) in the degreasing fluid (methylene chloride).

3.5.2 Rinse the cleaned cells twice with methyl alcohol or equivalent and allow to air-dry.

NOTE: Plastic gloves should be worn during the following operation.

3.5.3 Using masking tape, mask the cells in the areas where the finish is to be omitted. Consult Engineering Drawing 213831 for exact details.

3.5.4 Identify per WDL Standard 88-7009, Type II. Bag and tag with Part Number 211530-01 and Maufacturing Serial No. 100X.

3.6 Preparation of Mylar Insulation, Reference Engineering Drawing 213831.-

NOTE: Plastic gloves should be worn during the following operation.

3.6.1 Cut the Mylar sheet to the pattern configuration resulting from Shop Aid No. 0102.

3.6.2 Fold and crease the Mylar cut-out utilizing Shop Aid No. 0103. Consult Engineering Drawing 213831 for the bend-line locations.

3.6.3 Form and immobilize the insulator utilizing Shop Aid No. 0104. Apply the 23-P12351-0003 adhesive to the mylar over-lay. Allow adhesive to cure for a minimum of 24 hours at room temperature. Remove insulator jacket from tooling, strip excess adhesive, and clean with alcohol.

3.7 Modified Cell Preparation, Reference Engineering Drawing 213831.-

NOTE: Plastic gloves should be worn during the following operation.

3.7.1 Fit and install the Mylar insulation onto the cells per Engineering Drawings 213831-01 and 213831-02.

3.7.2 Identify per WDL Standard 88-7009, Type II. Bag and tag with Part Number 213831-XX and Manufacturing Serial No.

3.8 Final Battery Assembly, Reference Engineering Drawing 213827.-

3.8.1 Select ten 213831-01 cells and ten 213831-02 cells which have been previously processed.

3.8.2 Pre-align the cells, support ribs, support blocks, end plates and nut and bolt assemblies in the Battery Assembly Alignment Fixture, Shop Aid No. 0100. Shim cells with 05-P12097-XXXX Mylar as required.

3.8.3 Tighten alternate bolt assembly and rib hold-down rails to the figure configuration shown on the 213827 Engineering Drawing.

3.8.4 Torque alternately to 10 inch-lbs. and then to the final value of 12 to 15 inch-lbs. per WDL Standard 88-6111.

3.8.5 Attach safety wire four places per WDL Standard 88-7011, Class A, Type III. Trim excess Mylar insulator flush with top of cells for each support block.

3.8.6 Place battery assembly into Battery Mounting Hole Drilling Fixture, Shop Aid No. 0101. Drill the twelve bolt holes per Engineering Drawing 213827.

3.8.7 Bond the support blocks to the assembly with a mixture of 23-P12146-0001 epoxy resin, 23-P12137-0001 hardener, and 11-12013-0001 silica as follows:

De-air resin material and vacuum dry silica material at 150°F for 30 minutes. Mix an adhesive batch of 100 parts by weight of resin, 30 parts by weight of hardener, and a maximum of 4 parts by weight of silica for thickening. De-air batch after mixing thoroughly. Bond the support blocks to the assembly per WDL Standard 88-4002, Type II. Allow to cure at room temperature for a minimum of 24 hours.

3.8.8 Thermal vacuum dry the battery assembly at 90°F + 5°F and a minimum of 20 in. Hg vacuum for a minimum of 3 hours. Seal all dissimilar metal interfaces with 23-P12351-0003 adhesive. Allow to cure at room temperature for a minimum of 24 hours.

3.8.9 Prepare to apply paint to areas indicated by $\boxed{6}$ on Engineering Drawing 213827. Using masking tape, mask the areas where the finish is to be omitted. Note the areas where the finish is to be omitted; i.e., top of center support blocks, end plate connector mounting surfaces, bottom of battery and thermistor mounting surfaces. Note that the battery mounting screw holes are to be finished on the inside. (Note: Diagram cell position by serial number before application of paint).

3.8.10 Apply the 11-020054-0001 paint per WDL Standard 88-3016, Type II, Grade A. Following the drying of the paint, remove the masking tape.

3.8.11 Mark and identify battery end plate and individual cells as indicated by Engineering Drawing 213827 notes 15; 16; 17 and 18.

3.8.12 Pre-wire the connector and the battery cell interconnections, and install shrink sleeving in accordance with Engineering Drawings 211103 and 213828, and per NPC 5300.4 (3A).

3.8.13 Install the pre-wired 41-P10052-0008 connector to the 20-213829-01 end plate. Torque the connector screws to a value of 1.0 to 2.0 inch pounds per WDL Standard 88-6111, Table 3.

3.8.14 Complete the entire cell wiring per Engineering Drawings 213827 and 213828.

3.8.15 Attach lug to case ground wire. Crimp per WDL Standard 88-5011. Install lug per Engineering Drawing 213827.

3.8.16 Lace the wiring using 12-020056-0001 lacing per WDL Standard 88-5519, Type II, Class B.

3.8.17 Prepare a mixture of 23-P12146-0001 epoxy resin 23-P12137-0001 hardener, and 11-P12013-0001 silica as detailed in Paragraph 3.8.7. Bond the wiring to the support block interface per Engineering Drawing 213827. Conformally coat wiring (at support blocks), and case ground lug and bolt assembly. Allow to cure for 24 hours minimum at room temperature.

3.8.18 Prepare to install the two 52-P11050-0001 thermistors. Bond the thermistors utilizing adhesive 23-P12351-0003. Allow to cure at room temperature for a minimum of 24 hours. Seal all reminaing dissimilar metal surfaces.

3.8.19 Prepare to apply paint to remaining areas indicated by 13 on Engineering Drawing 213827. Areas to be finished are the epoxy-covered wire areas and the tops of cell therminal solder lugs. Mask as required.

3.8.20 Apply the 11-020054-0001 paint per WDL Standard 88-3016, Type II, Grade A. Following the drying of the paint, remove any remaining masking tape.

3.8.21 The final dimensions and battery weight shall be verified per Engineering Drawing 213827 values.

3.8.22 Place the completed battery assembly in the Battery Storage Box.

3.8.23 Store the battery assembly and its storage box at 70 ± 15°F ambient temperature.

3.8.24 Remove from storage and test per Acceptance Test Procedure SB 213716.

4.0 QUALITY ASSURANCE

4.1 The assembly shall be performed under the cognizance of Quality Control per NHB 5300.4 (1B).

APPENDIX L

SMS BATTERY ASSEMBLY QUALIFICATION TEST, DETAILED SUMMARY

3.1.1

SMS BATTERY ASSEMBLY
QUALIFICATION TEST
DETAILED SUMMARY

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
EXAMINATION OF PRODUCT				
Workmanship	5/15/72		MIL-STD-454 reqt	Acceptable
Construction	5/15/72		SD-212066	Acceptable
Interchangeability	5/15/72		Dwg. 213827	Acceptable
Weight	6/19/72		$\leq$ 3.58 kg	3.42 kg
Dimension	5/15/72		Dwg. 213827	Acceptable
FUNCTIONAL PERFORMANCE				
Insulation Resistance	5/15/72		$\geq$ 10MΩ @ +100V $\geq$ 10MΩ @ + 10V $\geq$ 10MΩ @ + 1V	$>$ 10^3MΩ $>$ 10^3MΩ $>$ 10^3MΩ
ELECTROLYTE LEAKAGE	5/15/72		Colorless	Colorless
Reconditioning				
Initial Charge	5/15/72 1600	Charge time: 40 hrs. Current:c/10(0.300 amp) Temp: 24^{o}C	Max. battery voltage determined by Fig. 1, SY-212789A	End of charge voltage Battery: 27.86V Cell min.: 1.393V Cell max.: 1.398V
Initial Discharge	5/17/72 0805	Current:c/2 (1.50 amp) Temp: 24^{o}C	Capacity: $\geq$ 3AH Battery Volt Limit: 20, +0, -1.5V Cell Volt Limit: 0.7V $\pm$ .3V	Capacity: 3.05AH End of discharge voltage Battery: 20.17V Cell min.: .70V Time: 2.03 hrs.
1Ω resistors on	5/17/72 1010	Load Applied 16 $\pm$ 0.5 hrs.		
1Ω resistors off	5/18/72 1000			

3.1.1 **(Continued)**

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
Secondary Charge	5/18/72 1600	Charge Time: 16 hrs. Current: c/10 (0.300 amp) Temp: 24°C	Max. battery voltage determined by Fig. 1 SY-212789A	End of charge voltage Battery: 28.34V Cell min.: 1.416V Cell max.: 1.422V
Secondary Discharge	5/19/72 0820	Current: c/2 (1.50 amp)	Capacity: ≥ 3.0AH Battery volt limit: 20, +0, -1.5V Cell volt limit: .7 ± .3V	Capacity: 3.44AH End of discharge voltage Battery: 19.12V Cell min.: .840V Time: 2.29 hrs.
1Ω resistors on	5/19/72 1502	Load applied 16 ± 0.5 hrs.		
1Ω resistors off	5/20/72 1500			
Short on	5/20/72 1500	Short on for 1 hr.		
Thermistor Performance	5/21/72 0800	Temp: 2 ± 2°C Stabilization period: 15 hrs.	Max. R : 41,993 Min. R : 40,397	R1 : 41,132 R2 : 40,539
	5/21/72 2400	Temp: 33 ± 2°C Stabilization period: 15.5 hrs.	Max. R : 11,154 Min. R : 10,716	R1 : 11,128 R2 : 10,925
	5/22/72 1600	Temp: 20 ± 2°C Stabilization period: 15.5 hrs.	Max. R : 18,146 Min. R : 17,434	R1 : 17,725 R2 : 17,460
Capacity Charge	5/22/72 1630	Charge time: 19.5 hrs. Current: c/10(0.300 amp) Temp: 20°C	Max. battery voltage determined by Fig. 1 SY-212789A	End of charge voltage Battery: 28.47V Cell min.: 1.441V Cell max.: 1.460V

3.1.1 (Continued)

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
Discharge	5/25/72 1300	Current: c/2(1.50 amp) Temp: 20°C	Capacity: $\geq$ 3.0AH Battery volt limit: 20, +0V, -1.5V Cell volt limit: .7 $\pm$ .3V	Capacity: 3.84AH End of discharge voltage Battery: 20.00V Cell min.: .775V Time: 2.56 hrs.
1Ω resistors on	5/23/72 1600	Load applied 16 $\pm$0.5 hrs.		
1Ω resistors off	5/24/72 0745			
Short on	5/25/72 0800	Short on for 1 hr.		
Low Temp Capacity Charge	5/24/72 1415	Charge time: 47.5 hrs. Current:c/20 (0.150 amp) Temp.: 2°C	Battery volt max:31.0V Cell vol max.: 1.55V	End of charge voltage Battery: 30.36V Cell min.: 1.510V Cell max.: 1.529V
Discharge	5/24/72 1405	Current: c/2(1.50 amp) Temp: 2°C	Capacity: $\geq$ 2.25AH Battery volt limit: 20, +0V, -1.5V Cell volt limit: .7 $\pm$ .3V	Capacity: 3.5^2 AH End of discharge voltage Battery: 20.2V Cell min.: .680V Time: 2.35 hrs.
1Ω resistors on	5/26/72 1700	Load applied 16.0 $\pm$0.5 hrs.		
1Ω resistors off	5/27/72 0853			
Short on	5/27/72 0900	Short on for 1 hr.		
High temp capacity Charge	5/27/72 1536	Charge time: 19.5 hrs. Current:c/10 (0.300 amp) Temp: +33°C	Max. battery voltage determined by Fig. 1 SY-212789A	End of charge voltage Battery: 27.50V Cell min.: 1.377V Cell max.: 1.389V
Discharge	5/28/72 1200	Current:c/2 (1.50 amp) Temp: +33°C	Capacity $\geq$ 1.5AH Batt volt limit: 20, +0, -1.5V Cell volt limit: 0.7 $\pm$ .3V	Capacity: 2.24AH End of discharge voltage Battery: 18.61V Cell min.: .700V Time: 1.49 hrs.

3.1.1 (Continued)

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
VIBRATION				
Pre-Vibration Charge	5/28/72 1400	Charge time: 42 hrs. Current:c/10(0.300 amp)	Max. battery voltage determined by Fig. 1, SY-212789A	End of charge voltage Battery: 27.99V Cell min.: 1.397V Cell max.: 1.410V
Discharge Volt Stability (Sinusoidal Vibration)	5/30/72 1628	Axis X-X Axis Y-Y Axis Z-Z	$\pm$0.25V/Minute Max.	Battery Voltage Range $\pm$.045V/Minute $\pm$.040V/Minute $\pm$.050V/Minute
Visual Damage	5/30/72 1730		No evidence	No damage
Discharge Volt Stability (Random Vibration)	5/30/72 1741	Axis X-X Axis Y-Y Axis Z-Z	$\pm$0.25V/Minute Max.	Battery Voltage Range $\pm$.040V/Minute $\pm$.030V/Minute $\pm$.050V/Minute
Visual Damage	5/30/72 1815		No evidence	No damage
POST VIBRATION PERFORMANCE				
Capacity Discharge	5/30/72 1822	Current:C/2(1.50 amps) Temp.: 24°C	No requirement	
1Ω resistors on	5/30/72 1955	Load Applied 16 $\pm$ 0.5 hrs.		
1Ω resistors off	5/31/72 1200			
Short on	5/31/72 1200	Short on for 1 hr.		

3.1.1 (Continued)

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
Charge	5/31/72 1305	Charge time: 20 hrs. Current:C/10(0.300 amp) Temp.: 24°C	Max. voltage determined by Fig. 1, SY-212789A	End of charge voltage Battery: 28.75V Cell min.: 1.430V Cell max.: 1.449V
Discharge	6/11/72 1000	Current:C/2(1.5 amps) Temp.: 20°C	Capacity: ≥ 3.0AH Battery Volt Limit: 20 + 0, -1.5V Cell Volt Limit: .7 ± .3V	Capacity: 3.59AH End of discharge voltage Battery: 20.0V Cell min.: .750V Time: 2.39 hrs.
Insulation Resistance	6/1/72 1300		≥ 10M @ +100V ≥ 10M @ +10V ≥ 10M @ +1V	> 10^3MΩ > 10^3MΩ > 10^3MΩ
ACCELERATION				
Pre-Acceleration Charge	6/1/72 1330	Charge time: 20 hrs. Current:C/10(0.300 amp)	Max. voltage determined by Fig. 1,SY212789A	End of charge voltage Battery: 28.04V Cell min.: 1.400V Cell max.: 1.412V
Discharge Volt Stability	6/2/72 1057	Axis X-X Axis Y-Y Axis Z-Z	±0.25V/Minute	Battery Voltage Range ±.04V/Minute ±.05V/Minute ±.04V/Minute
		TEST SETUP MALFUNCTION		
REWORK DATA				
Pre-Rework Discharge	6/2/72 1630	Current:C/2(1.5 amp) Temp.: 24°C	Battery Volt Limit: 20 + 2, -1.5V	End of discharge voltage Battery: 20.7V Cell min.: 0.4V Cell max.: 1.75 hr.
1Ω resistor on	6/2/72 1817	Load Applied 16 ± 0.5 hrs.		
1Ω resistor off	6/3/72 1030			

3.1.1 (Continued)

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
Post-Rework Capacity Charge	6/5/72 1620	Charge time: 19.5 hrs. Current:C/10(0.300 amp) Temp.: 20°C	Max. voltage determined by Fig. 1, SY212789A	End of discharge voltage Battery: 27.0V Cell min.: 1.415V Cell max.: 1.428V
Discharge	6/6/72 1245	Current:C/2(1.50 amp) Temp.: 20 C	Capacity: ≥3.0AH Battery Volt Limit: 20 + 0, -1.5V Cell Volt Limit: 7 ± .3V	Capacity: 3.54AH End of discharge voltage Battery: 18.6V Cell min.: 0.40V Time: 2.35 hrs.
SECONDARY VIBRATION AND ACCELERATION				
Pre-Vibration Charge	6/6/72 1520	Charge Time: 19.5 Hours Current: C/10 (0.300 Amp) Temp: +24°C	Max Voltage Deter- mined by Fig. 1, SY2117 9A	End of Charge Voltage Battery: 28.13V Cell Min: 1.404V Cell Max: 1.4.6V
Discharge Volt Stability (Sinusoidal Vibration)	6/7/72 1140	Axis X-X Axis Y-Y Axis Z-Z	±0.25 V/Minute	Battery Voltage Range ±.05V/Min ±.06V/Min ±.045V/Min
Visual Damage	1330		No Evidence	No Damage
Discharge Volt Stability (Acceleration)	6/7/72	Axis X-X Axis Y-Y Axis Z-Z	±0.25V/Minute	Battery Voltage Range ±.045V/Min ±.055V/Min ±.055V/Min
Visual Damage	6/7/72 1430		No Evidence	No Damage

3.1.1 (Continued)

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
POST ACCELERATION				
Capacity Discharge	6/7/72 1500	Charge Current: C/2(1.50 amps)	No requirement	
1Ω resistors on	6/7/72 1700	Load Applied 16 ± 0.5 hrs.		
1Ω resistors off	6/8/72 0900			
Short on	6/8/72 0900	Short applied for 1 hr.		
Charge	6/8/72 1200	Charge Time: 20 hrs. Current:C/10(0.30 amp)	Max. Voltage Determined by Fig. 1, SY212789A	End of Charge Voltage: Battery: 29.36V Cell Min.: 1.456V Cell Max.: 1.484V
Discharge	6/9/72 0900	Current:C/2(1.50 amps) Temp.: 20°C	Capacity: 3.0AH Battery Volt Limit: 20 + 0, -1.5V	Capacity: 3.72AH End of discharge voltage Battery: 18.5V Cell Min.: .670V
Insulation Resistance	6/9/72		≥ 10M @ +100V ≥ 10M @ +10V ≥ 10M @ +1V	> 10^3MΩ > 10^3MΩ > 10^3MΩ
THERMAL VACUUM				
Pre-Thermal Vacuum Charge	6/9/72 1315	Charge Time: 20 hrs. Current:C/10(0.300 amp) Temp.: 20°C	Max. Voltage Determined by Fig. 1, SY212789A	End of Charge Voltage: Battery: 28.14V Cell Min.: 1.406V Cell Max.: 1.418V
Thermistor Performance	6/11/72 1340	Temp.: 20 ± 2°C	34.5°F TC#2 36.1°F 34.8°F TC#4 36.4°F	36.1°F 36.0°F
	6/12/72 1000	Temp.: 33 ± 2°C	88.4°F TC#2 89.9°F 88.6°F TC#4 90.1°F	89.5°F 89.5°F
	6/13/72	Temp.: 20 ± 2°C	67.25°F TC#2 69.00°F 67.5°F TC#4 69.2°F	68.5°F 68.7°F

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3.1.1 (Continued)

TEST	DATE TIME	CONDITIONS	REQUIREMENTS	RESULTS
Temperature Performance		Discharge Current: C/2 (1.50 amp) Time: 1 minute Charge Current: C/10 (0.300 amp) Time: 10 minutes		
	6/10/72 1653	Temp.: 2 + 2°C	Min. battery voltage: 24V	26.01V
	6/11/72 1652	Temp.: 33 + 2°C		25.99V
	6/12/72	Temp.: 20 ± 2°C		25.36V
POST-THERMAL VACUUM Insulation Resistance	6/13/72		≥ 10M @ 100V ≥ 10M @ 10V ≥ 10M @ 1V	> 10^3 MΩ > 10^3 MΩ > 10^3 MΩ
Pulse Load 5 Min. Pulse	6/13/72	5 Minute Pulse Current: 10 amperes Temp.: 20°C	Min. battery voltage: 20V Min. cell voltage: 1V	21.48V 1.070V
10 Second Pulse		10 Second Pulse Current: 25 amperes Temp.:	Min. battery voltage: 20V Min. cell voltage: 1V	20.13V 1.012V
Full Charge Voltage Pre-charge	6/13/72 1200	Charge Time: 20 hrs. Current: C/10 (0.300 amp) Temp.: 24°C	No requirement	
30°C Overcharge	6/14/72 1400	Temp.: 30°C Current: C/10 (0.300 amp) Time: 3.5 hrs.	Max. battery voltage: 29.6V Max. cell voltage: 1.48V	27.69V 1.392V
10°C Overcharge	6/14/72 1120	Temp.: 10°C Current: C/15 (0.200 amp)	Max. battery voltage: 30.2V Max. cell voltage: 1.51V	29.58V 1.490V

APPENDIX M

SMS BATTERY ASSEMBLY ACCEPTANCE TEST PROCEDURE SB-213716

Ford Aerospace &
Communications Corporation
Western Development Laboratories Division
3939 Fabian Way
Palo Alto, California 94303

PROCEDURE NO. SB-213716 C

Code Ident. No. 11530

Title

SMS

BATTERY ASSEMBLY

ACCEPTANCE TEST PROCEDURE

12-9-77

PD

C

Program/Site SMS

Prime Contract Number NAS 5-21575

Spec. Engr.	Fred Dagg...	Date 3/31/77	Program Office	Barry T. Smith	3/31/77
Resp. Engr.	[illegible]	3/31/77	SRB Chairman	Barry T. Smith	3/31/77
Quality Assurance	W. C. Dorn	3/31/77	NASA GSFC APPROVAL	[illegible]	15 APR 77
			Release Date	ENGR DATA APR 18 1977	Page 1 of 161

WDL-572A
6-75

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Aeronutronic Ford **CHANGE RECORD**

CHANGE NUMBER	REASON FOR CHANGE	AFFECTED PAGE
Revision C	Incorporates comments from DCAS CN's 01871, 05841.	5, 7, 12, 13, 14, 15, 16, 17, 20, 21, 22, 23,24,25,27,28, 31, 32, 35, 58, 67, 81, 90, 92, 100, 122, 125, 138, 155, 160, 161

A vertical line in the margin indicates the changes in the latest revision.

WDL 120
10/76

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

1.0 SCOPE

1.1 This Procedure establishes the electrical and environmental performance requirements for the acceptance testing of the sealed nickel-cadmium battery assembly for use on the synchronous meterological satellite (SMS) program. Battery assemblies designated as flight models shall be subject to the tests described herein and shall meet all performance criteria set forth in Philco-Ford Power Subsystem Test Plan, Specification SA-212067.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents of the latest applicable issue, constitute a part of this procedure to the extent specified herein. Should a conflict exist, this procedure shall govern.

SPECIFICATIONS

Philco-Ford

SD-212061	SMS Power Control Unit, Design Specification
SD-212066	Battery Assembly, Design Specification
SA-212067	SMS Power Subsystem Test Plan
SC-213772	SMS Battery Assembly Procedure

STANDARDS

Military

MIL-STD-454 Requirement 9	Standard General Requirements for Electronic Equipment

DRAWINGS

Philco-Ford

211103	SMS Battery Assembly, Interface Control Drawing
211530	Battery Cell Drawing
213827	SMS Battery, Assembly Drawing

PLANS

Philco-Ford

TR 4487	SMS Quality Assurance Program Plan

3.0 REQUIREMENTS

3.1 Design Description.- The battery assembly, Philco-Ford part number 40-213827-01, shall consist of twenty hermetically sealed three ampere-hour nickel cadmium cells, Philco-Ford part number 82-211530-01. The assembly shall have been fabricated in accordance with Philco-Ford procedure number SC-213772 and shall meet the requirements of Philco-Ford SMS Battery Assembly Design Specification SD-212066.

The battery shall supply energy for the SMS mission power profile including prelaunch, hold, abort, launch/ascent, solar eclipse and peak non-eclipse operations. The role of the battery in the electrical power subsystem is defined in the SMS Power Control Unit Design Specification SD-212061.

3.1.1 Weight.- The weight of the battery assembly shall not exceed 7.90 pounds as specified in Philco-Ford Interface Control Drawing 211103. The battery assembly shall meet the center of mass and weight adjust requirements delineated in Drawing 211103.

3.1.2 Electrolyte Leakage.- The battery assembly shall show no signs of electrolyte leakage when subjected to the conditions specified herein.

3.1.3 Corrosion Resistance.- All external surfaces of the battery assembly shall show no evidence of corrosion when exposed to the environmental conditions specified herein.

3.1.4 Interchangeability.- All battery assemblies designated as Philco-Ford part number 40-213827-01, shall be functionally and dimensionally interchangeable in accordance with Philco-Ford Assembly Drawing 213827 and Interface Control Drawing 211103.

3.1.5 Marking.- Each battery assembly shall have a nameplate identification and serial number in accordance with Specification SD-212066.

3.1.6 Workmanship.- Standards of workmanship shall meet or exceed MIL-STD-454, Requirement 9. Materials utilized in the battery assembly shall comply with these standards.

3.1.7 Construction.- The battery assembly shall be constructed in accordance with the requirements of Specification SD-212066, and Procedure SC-213772.

3.1.8 Insulation Resistance.- The battery insulation resistance shall be verified as specified herein. The minimum allowable impedance shall be 10 megohms at a potential of +100, (+10, -0) Vdc.

3.2 Battery Performance.-

3.2.1 Capacity.- The battery shall meet the following capacity test requirement, as shown in Table I.

TABLE I

SMS BATTERY ASSEMBLY CAPACITY PERFORMANCE REQUIREMENTS

Temp. (°C)	Discharge Current (Amps)	Discharge Time (Hrs)	Min. Voltage (Volts)	Min. Req'd. % Rated Cap. 100%=3 (Amp Hrs)
20 ±2	1.5	2.0	20.00	100%
2 ±2	1.5	1.5	20.00	75%
33 ±2	1.5	1.0	20.00	50%
5 to 30	1.5	1.7	20.00	85%

3.2.2 Charging.-

The battery shall be capable of being charged at the maximum charge rate of 0.3 amperes. The maximum permissible battery voltage for a given test temperature shall be as follows:

a) 20°C charge - battery voltage 30.40V

b) 33°C charge - battery voltage 28.60V

c) 2°C charge - battery voltage 31.00V

The battery shall be capable of accepting continuous overcharge currents up to 0.3 amperes for the room temperature and high temperature tests and 0.15 amperes for the low temperature test.

3.2.3 Retention of Charge.- Each cell shall be free of short circuiting paths between negative and positive terminals and shall maintain an open circuit voltage of no less than 1.16 volts when tested in accordance with 4.5.6.4. The cell shall meet the provisions of this paragraph when charged and discharged at the rates and periods specified in Paragraph 3.2.1 and 3.2.2.

3.2.4 Reconditioning.- The battery shall be capable of delivering the required capacity specified in Table I after being subjected to a reconditioning procedure. Reconditioning of the battery may be required depending upon the battery use history and shall initiated only upon notification and approval of the responsible engineer.

3.2.5 Discharge Voltage Stability.- The battery discharge voltage shall maintain a voltage stability of ± 0.25 volts over a one minute period while being subjected to the vibration levels defined in paragraph 3.2.10 and 3.2.11. The stability criteria shall be applied for the first 30 minutes of continuous discharge at a 1.5 ± 0.05 ampere rate after a 5 minute discharge period.

3.2.6 Thermistor Performance.- The resistance of the battery thermistor shall be within 2% of the specified value in Table II, after being stabilized at the test temperature for a period of 16 hours. The battery test temperature range of 0° to 35°C shall be verified with a calibrated reference thermocouple.

3.2.7 Damage Inspection.- The Battery Assembly shall be capable of withstanding the environmental testing specified herein without evidence of physical damage. Damage of the assembly shall be considered to be any changes in the assembly structure or components.

3.2.8 Temperature Performance.- The battery discharge voltage shall meet or exceed a voltage level of 24.0 volts when discharged at a 1.5 ampere rate. The operating temperature range shall be from $+2^{\circ}$C to $+33$ C ($\pm 2^{\circ}$C) while being subjected to the thermal vacuum conditions of Paragraph 3.2.12. Recharge of the battery shall be accomplished with a 0.3 ampere charge rate except for low temperature tests such as 0°C when the charge current shall be 0.15 amperes.

REV	CHANGE	DATE	APPD
C	Removed configurations & added 1° temperature increments	11/27	[illegible]

TABLE II

15K 15O CURVE

TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω	TEMP °F	RESIST Ω
-50	521 250	0	106,900	50	28,250	100	9130	150	3467	200	1501	250	725.3	293	416.6	336	253.3	379	161.7	422	107.7	436	95.12
-49	[illegible]	1	103,900	51	27,580	101	8944	151	3406	201	1478	251	715.6	294	411.6	337	250.5	380	160.1	423	106.7	437	94.2[illegible]
-48	486,500	2	101,000	52	26,920	102	8761	152	3346	202	1456	252	706.1	295	406.7	338	247.8	381	158.5	424	105.7	438	93.48
-47	470,500	3	98,160	53	26,280	103	8583	153	3287	203	1433	253	696.7	296	401.7	339	245.1	382	157.0	425	104.8	439	92.[illegible]7
-46	454 7[illegible]	4	95,410	54	25,660	104	8408	154	3229	204	1411	254	687.4	297	396.9	340	242.4	383	155.5	426	103.9	440	91.[illegible]7
-45	439,[illegible]0	5	92,730	55	25,050	105	8236	155	3173	205	1390	255	678.2	298	392.1	341	239.8	384	154.0	427	102.9	441	91.[illegible]9
-44	424 50[illegible]	6	90,130	56	24,450	106	8068	156	3117	206	1369	256	669.2	299	387.4	342	237.2	385	152.5	428	102.0	442	90.32
-43	410 5[illegible]	7	87 600	57	23,870	107	7904	157	3062	207	1348	257	660.3	300	382.7	343	234.7	386	151.0	429	101.1	443	[illegible]
-42	39[illegible]	8	85 150	58	23,300	108	7743	158	3008	208	1327	258	651.5	301	378.2	344	232.2	387	149.5	430	100.2	444	8[illegible].79
-41	38[illegible]	9	82 760	59	22,750	109	7585	159	2955	209	1307	259	642.8	302	373.7	345	229.7	388	148.1	431	99.34	445	88.04
-40	370 6[illegible]	10	80,440	60	22,210	110	7430	160	2903	210	1287	260	634.2	303	369.3	346	227.3	389	146.6	432	98.48	446	87.25
-39	355 700	11	78 200	61	21 700	111	7[illegible]	161	2854	211	1268	261	626.0	304	364.9	347	224.8	390	145.2	433	97.63	447	86.55
-38	347 100	12	76 180	62	21 200	112	7[illegible]	162	2806	212	1249	262	617.6	305	360.6	348	222.4	391	143.8	434	96.78	448	85.81
-37	336 000	13	74,000	63	20 71[illegible]	113	6959	163	2758	213	1231	263	609.6	306	356.4	349	220.1	392	142.4	435	95.95	449	85.[illegible]
-36	325 100	14	72,050	64	20 230	114	[illegible]	164	2711	214	1213	264	601.9	307	352.1	350	217.7	393	141.1			450	84.36
-35	314 700	15	7[illegible]	65	19,750	115	6725	165	2665	215	1195	265	594.0	308	348.0	351	215.4	394	139.7				
-34	304 600	16	[illegible]	66	19 3[illegible]	116	6592	166	2620	216	1178	266	586.3	309	343.9	352	213.2	395	138.4				
-33	294,[illegible]0	17	66 330	67	18,860	117	6462	167	2576	217	1160	267	578.7	310	339.8	353	211.0	396	137.1				
-32	285,300	18	64 5[illegible]	68	18,420	118	6335	168	2532	218	1143	268	571.2	311	335.9	354	208.8	397	135.8				
-31	276 1[illegible]	19	62 7[illegible]	69	18,000	119	6210	169	2489	219	1127	269	563.7	312	332.1	355	206.6	398	134.5				
-30	267,200	20	61,37[illegible]	70	17 550	120	6067	170	2447	220	1110	270	556.4	313	328.2	356	204.5	399	133.2				
-29	258 900	21	59 [illegible]70	71	17,190	121	5971	171	2406	221	1094	271	549.3	314	324.5	357	202.3	400	131.9				
-28	250 90[illegible]	22	57 [illegible]	72	16,800	122	5856	172	2366	222	1078	272	542.3	315	320.8	358	200.2	401	130.7				
-27	243,100	23	56 3[illegible]	73	16,430	123	5744	173	2327	223	1062	273	535.4	316	317.1	359	198.2	402	129.5				
-26	235,500	24	54,910	74	16,060	124	5634	174	2289	224	1047	274	528.6	317	313.5	360	196.1	403	128.2				
-25	228,200	25	53 470	75	15,710	125	5527	175	2251	225	1032	275	521.9	318	309.9	361	194.1	404	127.0				
-24	221,100	26	52 [illegible]	76	15,350	126	5421	176	2213	226	1017	276	515.2	319	306.3	362	192.1	405	125.9				
-23	214 300	27	50,700	77	15,000	127	5317	177	2177	227	1002	277	508.7	320	302.8	363	190.2	406	124.7				
-22	207 60[illegible]	28	49,370	78	14,660	128	5216	178	2140	228	987.6	278	502.2	321	299.4	364	188.2	407	123.5				
-21	201,100	29	48,070	79	14,350	129	5116	179	2105	229	973.3	279	495.8	322	296.0	365	186.3	408	122.4				
-20	194 900	30	46 810	80	14,030	130	5018	180	2070	230	959.2	280	489.5	323	292.7	366	184.4	409	121.2				
-19	189 000	31	45,620	81	13,730	131	4925	181	2036	231	945.7	281	483.4	324	289.4	367	182.5	410	120.1				
-18	182,400	32	44 4[illegible]	82	13,430	132	4833	182	2003	232	932.4	282	477.4	325	286.2	368	180.7	411	119.0				
-17	177 600	33	43 340	83	13 140	133	4744	183	1971	233	919.3	283	471.5	326	283.0	369	178.8	412	117.9				
-16	172 300	34	42,240	84	12 860	134	4655	184	1939	234	906.4	284	465.7	327	279.8	370	177.0	413	116.8				
-15	167 300	35	41,170	85	12 590	135	4569	185	1908	235	893.7	285	459.9	328	276.7	371	175.2	414	115.8				
-14	162,300	36	40 120	86	12,[illegible]20	136	4484	186	1877	236	881.1	286	454.2	329	273.6	372	173.5	415	114.7				
-13	157 400	37	39,1[illegible]	87	12 050	137	4401	187	1846	237	868.7	287	448.6	330	270.5	373	171.8	416	113.7				
-12	152,600	38	38 113	88	11,790	138	4319	188	1816	238	856.5	288	443.0	331	267.6	374	170.0	417	112.7				
-11	148,100	39	37 14[illegible]	89	11,5[illegible]	139	4233	189	1787	239	844.5	289	437.5	332	264.6	375	168.3	418	111.6				
-10	143 600	40	36 200	90	11,29[illegible]	140	41[illegible]	190	1758	240	832.6	290	432.1	333	261.7	376	166.7	419	110.6				
-9	139 420	41	35 310	91	11,050	141	40[illegible]5	191	1730	241	821.3	291	426.9	334	258.9	377	165.0	420	109.6				
-8	135 400	42	34 450	92	10,820	142	4011	192	1703	242	810.0	292	421.7	335	256.1	378	163.3	421	108.6				
-7	131 40[illegible]	43	33 600	93	10,590	143	39[illegible]	193	1677	243	79[illegible].8												
-6	127 6[illegible]	44	32 760	94	10,370	144	3868	194	1650	244	787.9												
-5	123 9[illegible]	45	31,980	95	10,150	145	3798	195	1624	245	777.1												
-4	120 3[illegible]	46	31,200	96	9,939	146	3729	196	1599	246	766.5												
-3	116 800	47	30,430	97	9 731	147	3662	197	1574	247	756.0												
-2	113 400	48	29,690	98	9,526	148	3596	198	1549	248	745.6												
-1	110 100	49	28 960	99	9,326	149	3581	199	1525	249	735.4												

CAUTION:

THE RESISTANCE VALUES LISTED are precise nominal values for all types of matched pairs of standard configuration when tested and used in the proper manner. For standard configurations and applicable corrections of nominal resistance due to varied lead lengths and test points, refer to F.E.I. dwg. entitled "Matched Pair Standard Configurations".

FENWAL ELECTRONICS INC.

FRAMINGHAM MASS

TITLE 15K 15O CURVE

TOLERANCES

DR 1L 11/27/63

NO. P 6134 Rev. C — C

TABLE II

M-10

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3.2.9 Pulse Load.- The minimum allowable battery discharge voltage for the following pulse load conditions shall be 18.5 volts and the cell voltage shall exceed 0.70 volts. The battery shall be initially fully charged and at a temperature of 24 $\pm 5^{\circ}$C when subject to a pulse load of 25.0 amperes for a period of 10 seconds followed by a load of 10.0 amperes for 5 minutes. The time interval between the first and second pulse shall be greater than 1.0 minute.

3.2.10 Sinusoidal Vibration.- The battery shall be subjected to a sinusoidal vibration test in accordance with Table III and Figure 1. The ZZ axis is interpreted as the thrust axis of the satellite.

3.2.11 Random Vibration.- The battery shall be subjected to a random vibration test in accordance with Table IV and Figure 1. The ZZ axis is interpreted as the thrust axis of the satellite.

3.2.12 Thermal Vacuum.- The purpose of this test is to demonstrate the battery performance capability under vacuum and temperature stress more severe than predicted orbit conditions. Specific test temperatures for the battery are given in Paragraphs 3.2.6 and 3.2.8. Simulation of space vacuum condition shall be accomplished by reducing the chamber pressure to 1 x 10^{-5} Torr.

3.3 Test Preparation.-

3.3.1 Test Apparatus.- All meters, scales, thermometers, and other test equipment used in conducting tests specified herein shall be accurate within 1% of the full scale value. Full scale deflections of meters should be not more than twice the maximum value of the quantity being measured. Periods of charge and discharge shall be timed with a device accurate to within 1.0%. All test apparatus shall be calibrated at suitable intervals against standards whose calibration is traceable to the National Bureau of Standards or equivalent. Records of such calibrations shall be available for inspection.

3.3.2 Records.- Records shall be kept and made available for inspection of the tests and of applicable manufacturing data. All test parameters shall be monitored on a continuous basis (i.e., temperature, current, voltage).

3.3.3 Test Conditions.- Unless otherwise stated, laboratory ambient conditions of tests shall be:

a. Temperature 24 $\pm 5^{\circ}$C.

b. Barometric Pressure 30 ± 2 inches of mercury.

c. Relative humidity less than 90%.

TABLE III

BATTERY ACCEPTANCE
SINUSOIDAL VIBRATION

DESCRIPTION	FREQUENCY RANGE (HZ)	LEVEL "g" (0 to Peak)	TEST SWEEP (Oct/Min)
Components on Equipment	5-10	.5" DA	
Panel (XX, YY)	10-20*	10.0	
	20-25	4.0	4.0
	25-40	8.0	
	40-100	4.0	
	100-200	2.0	
	200-2000	5.0	
Components on Equipment	5-11	.5" DA	
Panel (ZZ)	11-13*	7.0	
	13-30	12.5	4.0
	30-60	25.0	
	60-70	15.0	
	70-110	8.0	
	110-200	3.0	
	200-2000	5.0	

*Due to vibration exciter limitations, a minimum of 0.5" DA is acceptable provided the item is resonance free over this region and a steady state load equal to the specified vibration load is exerted on the item at some time during the test program. If it does not react as a rigid body, it must be demonstrated by acceptable techniques that adequate margins of safety are inherent in its design.

TABLE IV

BATTERY ACCEPTANCE
RANDOM VIBRATION

AXIS	FREQUENCY RANGE (HZ)	PSD LEVEL (g^2/HZ)	ACCELERATION (g rms)	DURATION
X-X,	20-30	Roll-off below 30 Hz at rate of 6 dB/octave	7.9	2 minutes each axis
	30-300	0.08		
	300-600	Roll-off at rate of 6 dB per octave		
	600-2000*	0.02		

*The filter roll-off characteristics above 2000 Hz shall be at a rate of 40 dB/octave or greater.

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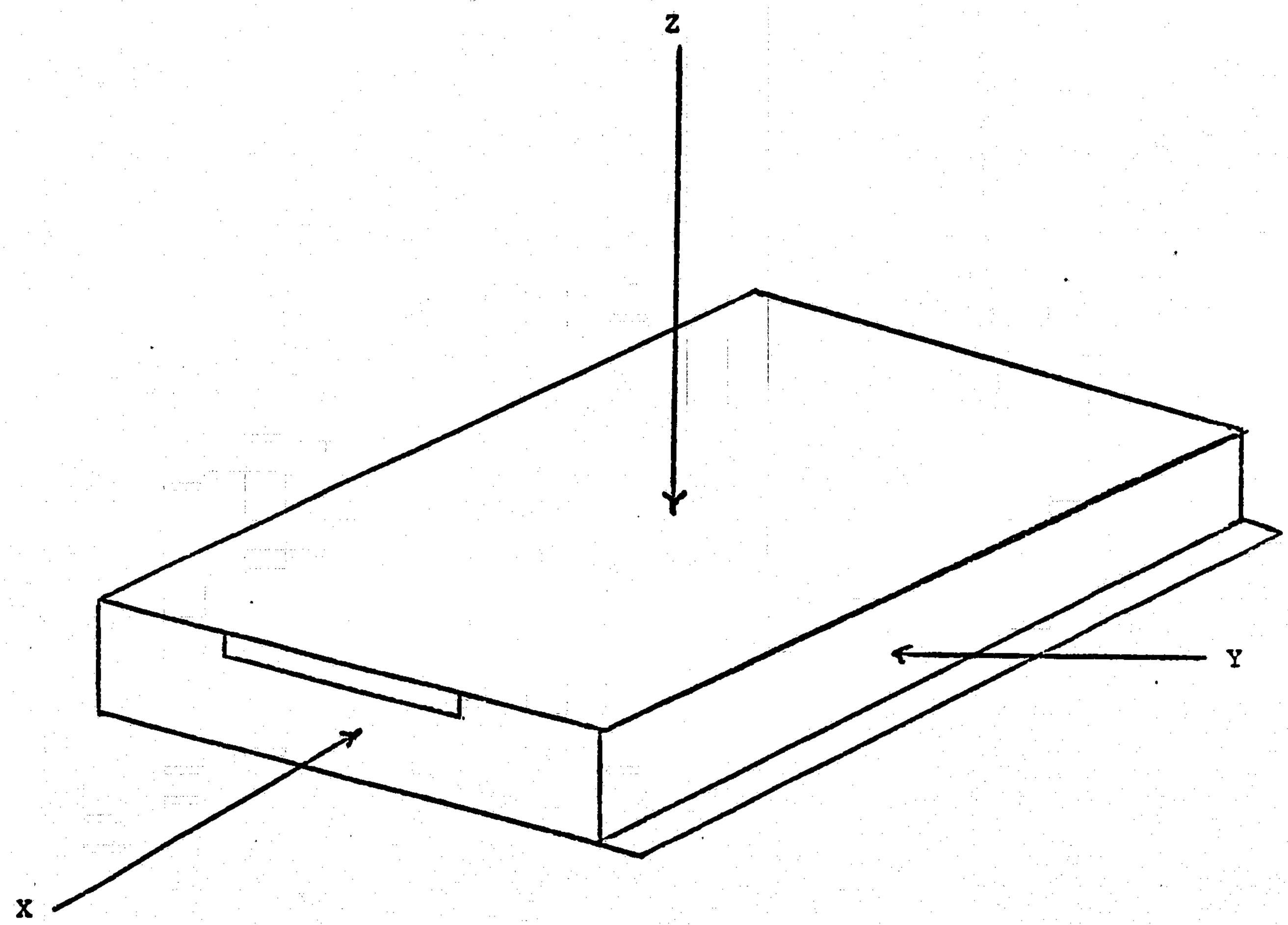

FIGURE 1

BATTERY ASSEMBLY AXES FOR VIBRATION

3.3.4. <u>Tolerances.-</u> Unless specifically stated in the test procedure the following test tolerances are allowable:

a. Temperature $\pm 5^{\circ}C$

b. Voltage $\pm 0.5\%$

c. Current $\pm 5\%$

d. Time $\pm 1.0\%$

3.3.5 <u>BTE Failsafe Circuit Protection Checkout.-</u>

3.3.5.1 <u>Pretest Verification.-</u> Prior to placing batteries in the temperature chambers the following tests shall be conducted.

a. Activate the charge and discharge power supply circuits. Connect the $40^{\circ}C$ upper limit and $10^{\circ}C$ lower limit sensors. Set the temperature limit control on the chamber to $30^{\circ}C$ and the temperature adjust control to $50^{\circ}C$. Observe and record on the data sheet that the chamber shuts off when $30^{\circ}C$ is reached.

b. Set the temperature limit control on the chamber to $50^{\circ}C$ and reset chamber power. Observe and record on the data sheet that both the chamber and power supplies shut off when $40^{\circ}C$ is reached. Return to ambient and reset the power supplies and chambers.

c. Set the temperature adjust control to $5^{\circ}C$. Observe and record on the data sheet that the chambers and power supplies shut off when $10^{\circ}C$ is reached.

d. Disconnect the $10^{\circ}C$ sensor and connect the -7° sensor. Reset the chamber and power supplies. Set the temperature adjust control to $-10^{\circ}C$. Observe and record that the power supplies and chambers shut off when $-7^{\circ}C$ is reached. Return to ambient. Disconnect the $-7^{\circ}C$ sensor and reconnect the $10^{\circ}C$ sensor. Reset failsafe circuits.

e. Reset cells 1 through 24 and battery. All enable switches should be on. Step through all positions. Observe and record that each "out" light comes on.

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3.3.5.2 <u>In Process Verification of Failsafe Circuits.-</u> These tests are to be performed at the appropriate place in functional tests.*

a. Power Interrupt Protection - activate the BTE main power and battery temperature chambers. Momentarily remove the power to BTE and temperature chambers. Observe and record that the BTE and all temperature chambers remain off.

b. Volt Sensor Operation - Verify that charge power supplies are off. Place enable switches on for cell positions 21 through 23. Activate cells 21 through 23 and manually step to these positions. Observe and record that "out" lights for these positons come on.

c. Verify that temperature limit adjust is set to 50°C. Program BTE charging power supplies to limit battery voltages to 31.1 ±0.1 volts. Note that charge line voltage losses of approximately 0.7 volts must be compensated for when setting charging power supply voltage limits.

*See Data Sheet pages 35, 58, 67, 81, 90, 92, 100, 125, 138 & 155 (Verify that cell undervoltage detector is set at 0.7±0.3 volts so that battery capacity determination can be made if battery undervoltage occurs other than during the specified 10 minute data printout interval. In this instance, capacity is determined by the elapsed tester timer.)

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General.- Quality Assurance shall be in accordance with TR-4487, SMS Quality Assurance Program Plan.

4.2 Acceptance Tests.- Acceptance tests are those tests conducted for the purpose of providing data to be used in the evaluation of the SMS batteries. The qualification tests shall be conducted in the sequence shown in the test matrix Table V. Tests shall include, but not necessarily be limited to, those shown on the test matrix.

4.3 Inspection.-

4.3.1 Battery Assembly.- The assembly shall be visually inspected for damage prior to and upon completion of each test specified in Table V. TFR/RMR procedures apply to all "unusual occurrences".

4.3.2 Notification.- The cognizant QA representative shall be notified at least 48 hours prior to the planned starting time of the test, so that timely notification of the customer representative can be provided.

4.3.3 Documentation.- Prior to the start of the test, the unit to be tested and the necessary documentation shall be submitted to the QA representative for review to verify test readiness. The documentation shall include at least the following:

TABLE V
ACCEPTANCE BATTERY TEST MATRIX

REF. PARA.	PERFORMANCE PARAMETERS	Examination of Product (4.5.1)	Functional (4.5.2)	Vibration - Sinusoidal (4.5.3)	Vibration - Random (4.5.3)	Post Vibration (4.5.4)	Thermal Vacuum (4.5.5)	Post Thermal Vacuum (4.5.6)
3.2.6	Thermistor Performance		X				X	X
3.2.3	Charge Retention							X
3.2.9	Pulse Load							X
3.2.12	Thermal Vacuum						X	
3.2.8	Temperature Performance						X	
3.2.2	Full Charge Voltage					X		
3.2.7	Visual Inspection for damage			X	X		X	
3.2.5	Discharge Voltage Stability			X	X			
3.2.11	Vibration, Random				X			
3.2.10	Vibration, Sinusoidal			X				
3.1.2	Electrolyte Leakage		X					X
3.2.1	High Temperature Capacitance		X					
3.2.1	Low Temperature Capacitance		X					
3.2.1	Capacity		X			X		X
3.2.4	Reconditioning		X					
3.1.8	Insulation Resistance		X			X		X
3.1.5	Identification	X						
3.1	Dimension	X						
3.1.1	Weight	X						
3.1.4	Interchangeability	X						
3.1.7	Construction	X						
3.1.6	Workmanship	X						

A log for each battery assembly shall be included. Each log shall be identifiable to the pertinent equipment and shall be maintained in chronological order to account for all fabrication, assembly, test and inspection operations; as well as idle periods (storage) and movements of the item. Entries shall be complete, self-explanatory and signed, and should include or refereto details such as the following:

a. Configuration data: parts list, drawings, specifications, changes, serial numbers, lot numbers.

b. Fabrication and assembly history: copies of build-up and disassembly instructions, repairs, rework, modifications.

c. Test and inspection records: copies of specifications, procedures, results, variables data.

d. Non-conformances summary: non-conformance list, MRB actions, failures, failure analyses, corrective actions.

e. Cumulative operating times or charge/discharge cycles shall be recorded on Data Sheet page 160.

A released and verified Battery Assembly Test Procedure.

The Battery Assembly drawing, shop order, kit list, etc.

4.3.4 Test Equipment Verification.- The QA representative shall verify that all test equipment to be used during the test carries evidence of valid calibration which will not expire during the expected duration of the test. Special test equipment (BTE) shall be accompanied by evidence that validation testing has been satisfactorily completed within the specified time period. Test equipment is listed in Table VI, and the test set-up is shown in Figure 2.

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TABLE VI

BATTERY TEST EQUIPMENT LIST

EQUIPMENT	MODEL OR PART NO. *
1. Section A control	SMS BTE - #71-12-868-4A
2. Section A access	SMS BTE - #71-12-868-4B
3. Power Source A	H/P 6271B, 6274B
4. Digital Monitor	H/P 562A
5. Digital Voltmeter	HP 3440 A
6. Megohm Meter	GENERAL RADIO 1644A
7. Temperature Recorder	YSI 80A with Jen No. YSI 8423-33
8. Digital Data System	VIDAR 5401
9. Temperature Chamber	MISSIMER FT8, FT4 or FT 1.5
10. Meg Ohm Bridge	ESI Pub. 300
11. Time Indicator	EVM T2B 720
12. Vacuum System	PHILCO FORD CVC PAS - 41B

*Note: Equivalent instruments may be substituded for the models listed.

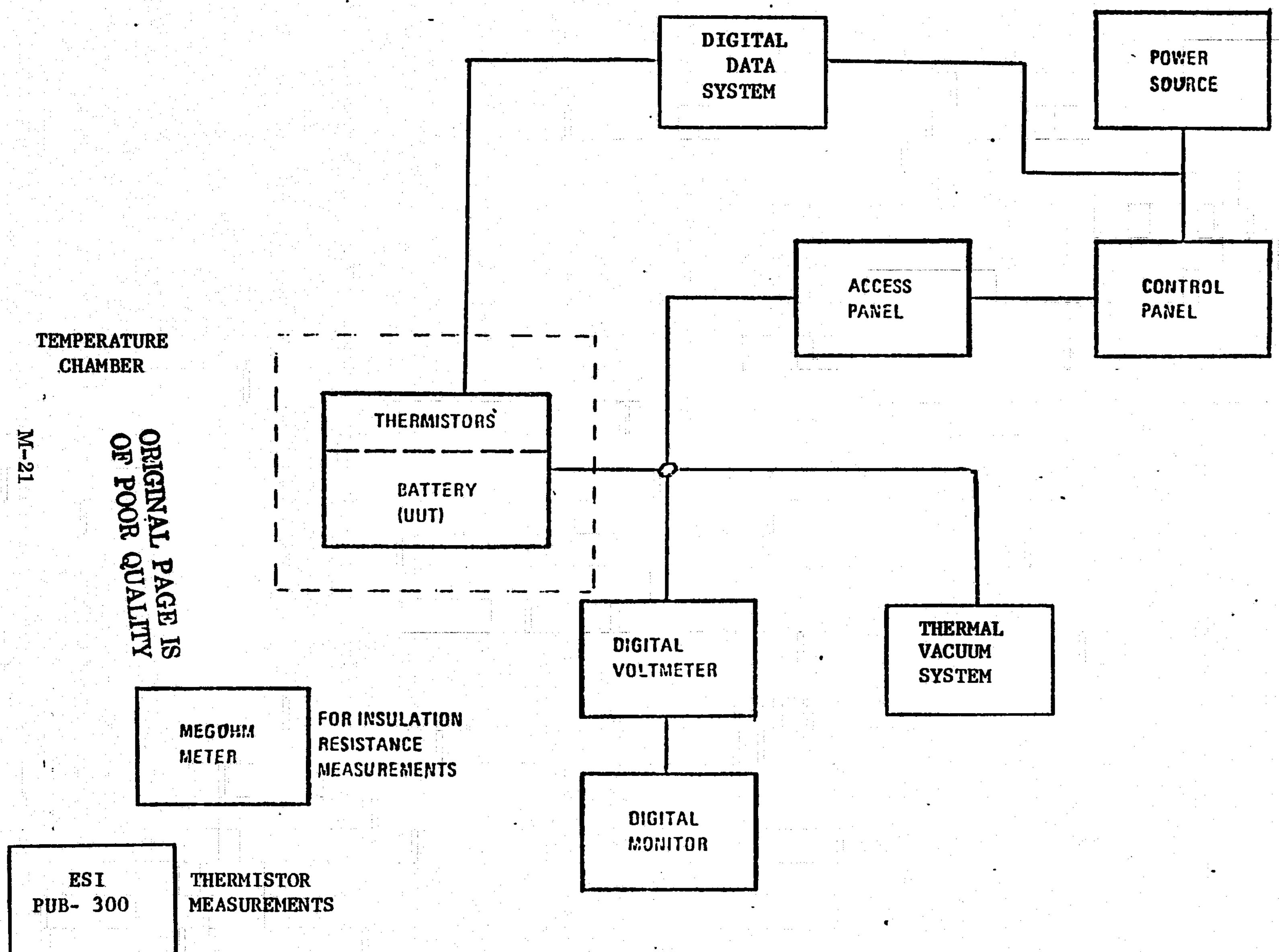

FIGURE 2 BATTERY BTE BLOCK DIAGRAM

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M-21

4.3.5 Test Surveillance.- Before the start of testing, the QA representative will verify the test set-up. During the test, the QA representative will monitor the test. He will also perform inspection of the unit under test as required by this Procedure. As a minimum, he shall indicate completion of each test sequence where surveillance is required and each test data page where witnessing is required by QA stamp.

4.4 Test Failure.-

4.4.1 Adjustment and Repair During Tests.- No adjustments, repairs or maintenance of the test article shall be allowed except as specified herein, or as directed by the Material Review Board.

4.4.2 Test Failure is defined as:

a. Functional equipment performance exceeding procedure limitations.

b. Intermittant or erratic end item equipment performance.

c. Overstress of end-item hardware caused by test equipment or test set-up when an evaluation of the effects of the overstress cannot or has not been determined.

d. Drift of equipment operating parameters which would, in all probability, exceed the procedure limit if equipment operation were to continue.

4.4.3 Test Failure Procedure.-

a. If the item under test fails, the test shall be suspended and the inspector shall verify that the cognizant test engineer has noted the failure on the test data sheets. The cognizant Quality Assurance and Government representatives shall be notified immediately. These representatives shall jointly determine if: (1) the unit shall be sent directly to the Material Review Board (MRB), (2) additional tests shall be conducted to determine the cause of failure then the unit routed to MRB, or (3) if the failure does not affect other test results, the tests continued and the failure resolved by MRB at the completion of the test, or when first received by the MRB. If agreement cannot be reached among the representatives, the unit will be routed to MRB.

4.4.3 Test Failure Procedure.- (Continued)

b. The quality inspector shall verify that each failure has been immediately recorded on a Request for Material Review/Trouble-Failure Report (RMR/TFR) from 4057A, and a copy sent to Reliability TFR Control.

4.4.4 Repair and Retest.- Following initial failure analysis, the procedure described below shall be followed:

a. After the cause of failure has been isolated, a repair and retest course of action shall be defined. The retest will normally repeat the test sequence during which the failure occurred. If the repair would affect results of previous tests, those tests shall be repeated. If test equipment fails during the test, the measurements that may have been affected by degraded performance of the test equipment, shall be repeated, or as authorized by the designated Philco-Ford QA representative or MRB.

b. The proposed repair and retest plan shall be submitted to MRB.

c. The Philco-Ford MRB shall review and approve the repair and retest plan prior to implementation.

d. The Philco-Ford Quality Assurance representative shall witness retest following repair under the conditions defined.

4.4.5 Test Equipment Failure.-

a. In the event of a test equipment failure that has caused, or most probably has caused, the unit under test to be over-stressed, the test equipment failure shall be considered an end-item failure, and handled in the same manner.

b. If the test equipment fails in a manner that is not hazardous to the item under test, the test failure will be documented on a Discrepancy Notice (DN) or RMR (via PMR action). Following inspection and verification that the test equipment set-up is working satisfactorily again, the DN or RMR may be closed.

4.5 Test Methods.-

4.5.1 Examination of Product.- Each complete battery assembly submitted for acceptance testing shall be inspected to determine compliance with this Procedure and drawing 213827 with respect to workmanship, construction, interchangeability, sealing, cell container, weight, dimensions, identification marking, packaging and packing, terminals, and center of mass.

4.5.2 Functional Performance.- Prior to beginning functional tests verify that BTE failsafe circuit checkout has been accomplished, paragraph (3.3.5.1)

4.5.2.1 Insulation Resistance.- The insulation resistance shall be measured between the following:

From	To
Battery case ground	Battery connector leads
Battery case ground	Cell case
Battery connector leads	Thermistor leads

The resistance between these points shall be at least 10 megohms at a potential of +100 (+10, -0) Volts dc. Measurement accuracy shall be $\pm$0.1 megohm. See data sheets in Appendix A for detail test steps.

4.5.2.2 Reconditioning Procedure. - If required, discharge the battery to 20 + 0, -1.5 volts or a cell voltage of 0.7 $\pm$ 0.30 volts at the C/2 rate (1.5 $\pm$ 0.05 amp), then short each cell with 1 ohm until all cell voltages are less than 0.2 volts, but for 4 hours minimum in any case and record data on Data Sheet, page 161. Recharge the battery for 40 $\pm$0.5 hours at the C/20 rate (0.15 $\pm$0.015 amps). After charging, discharge the battery to 20.0 + 0V, -1.5V or a cell voltage of 0.7 volts $\pm$0.30V at the C/2 rate, then place an one ohm resistor across each pair of cell terminals until all cell voltages are less than 0.2 volts, but for 4 hours minimum in any case. Charge the battery at 0.3 $\pm$0.015 amperes for 16 $\pm$0.5 hours. Discharge the battery to 20.0, +0.V, -1.5V or a cell voltage of 0.7V $\pm$0.3V at 1.5 $\pm$0.05 amps. Short each cell with an one ohm resistor for 24 $\pm$0.5 hours.

NOTE 1: Measurement accuracy shall be as specified in paragraph 3.3.4.
NOTE 2: Before proceeding with this test perform failsafe circuit checks a, b, c of paragraph 3.3.5.2.

4.5.2.3 Capacity.- Unless otherwise specified, the capacity test shall be performed at 20° ±2°C temperature. Ampere hour capacity shall be measured to the cutoff voltage given for the rate specified and shall not be less than the capability specified in 3.2.1. Discharge each battery to 20.0 +0. -1.5 volts or to cell voltage of 0.7 ±0.3 volts, and place a 1.0 ohm resistive load on each cell for 4 hours minimum or until all cell voltages are less than 0.2 volts. (Discharge cycle #2 of Paragraph 4.5.2.2 may be substituted for the discharge cycle.) The battery shall be charged at C/10 (0.30 ±0.015) ampere for 20 ±.5 hours then placed on a 1.0 ±0.1 hour open circuit stand. The discharge capacity shall be at least 3.0 ampere hours at C/2 (1.5 ±.05 amperes) rate to the specified cutoff voltage. At no time shall the discharge voltage fall below 18.5 volts, or cell voltage below 0.4 volts. If any cell voltage reaches 1.52 volts during charge, stop charging, (if cell voltage does not peak and drop below 1.52 V within one hour,) and proceed with discharge and submit data to MRB.

NOTES: 1. The battery charge voltage shall never exceed 30.40 volts.

2. Each cell voltage, and external battery case temperature shall be monitored continuously and recorded as follows:

a. Immediately prior and after start of each charge or discharge step.

b. At one hour maximum intervals during all charges.

c. At 15 minute maximum intervals during all discharges.

3. Measurement accuracy shall be as specified in Paragraph 3.3.4.

4. Before proceeding with this test perform failsafe circuit checks a, b, c of paragraph 3.3.5.2

4.5.2.4 Low Temperature Capacity.- The battery temperature shall be maintained at 2°C for a minimum of 5 hours prior to and during charge and discharge. Each cell shall be fully discharged with a 1 ohm load for 4 hours minimum or until all cell voltages are less than 0.2 volts, then stabilized at the test temperature. The battery charge voltage shall not exceed 31.0 volts during the 48 ±0.5 hours charge at 0.15 ±0.015 ampere rate. The deliverable capacity shall be at least 2.25 ampere hours at the C/2 rate (1.5 ±0.05 amperes) when the battery is discharged to a cutoff voltage of 20.0 +0, -1.5 volts or a cell voltage of 0.7 ±0.3 volts. Measurement accuracy shall be as specified in Paragraph 3.3.4. If any cell voltage reaches 1.55 volts during charge, if cell voltage does not peak and drop below 1.55 volts within one hour, stop charging and proceed with discharge and submit data to MRB.

NOTE: Before proceeding with this test, perform failsafe circuit checks a, b, c, of paragraph 3.3.5.2.

4.5.2.5 High Temperature Capacity.- With the battery temperature maintained at 33 $\pm 2^{\circ}$C during charging and discharging, the discharge capacity shall not be less than 1.5 ampere hours when charged at C/10 (0.3 $\pm$.015 ampere) for 20 $\pm$.5 hours placed on open circuit for one hour and discharged at the two hour rate (1.5 $\pm$0.05 amperes) to a battery cutoff voltage of 20.0 +0, -1.5 volts or a cell voltage of 0.7 $\pm$0.3 volts. Before charging, the battery shall be fully discharged with a 1.0 ohm resistor placed across the cell terminals for 16.0 $\pm$0.5 hours, and stabilized at the test temperature for 5 hours minimum. The maximum charging voltage shall not exceed 28.6 volts during the 20 $\pm$0.5 hour charge at 0.3 $\pm$0.015 ampere rate. If any cell voltage reaches 1.43 volts during charge, stop charging, if cell voltage does not peak and drop below 1.43 volts within one hour, and proceed with discharge and submit data to MRB.

NOTE: 1. The measurement accuracy shall be as specified in Para. 3.3.4.

2. Before proceeding with this test, perform failsafe circuit checks a, b, c of Para. 3.3.5.2.

4.5.2.6 Thermistor Performance. - The battery temperature shall be stabilized at each test temperature 2° C, 20° C and 33° C $\pm 2^{\circ}$ C for a minimum period of 5.0 hours as determined by a calibrated thermocouple. The resistance of the thermistor shall be within 2% of the required value shown in Table II after a minimum 5-hour stabilization period.

NOTE: 1. Before proceeding with this test perform failsafe circuit checks a, b, c of Para. 3.3.5.2.

4.5.2.7 Electrolyte Leakage.- This test shall occur immediately after completion of charge, during which the cell must have received a minimum of 4 hours of overcharge to assure a positive cell pressure with respect to atmospheric pressure. The initial leakage check shall be performed to verify the integrity of the cell seals prior to electrical performance testing. (Normally this test is performed following a charge per paragraph 4.5.2.3. Prior to start of charge, the cell shall be thoroughly cleaned with distilled water and alcohol. All mechanically sealed areas on the cell, including cell welds and fill tube pinch off welds, shall be washed with a solution of 0.5% phenolphthalein in 50% alcohol and 50% distilled water. If no red indication occurs due to application of the phenolphthalein solution, the cells shall again be cleaned with distilled water and alcohol. Immediately after completion of a charging period, which includes an overcharge, the cells shall again be swabbed with phenolphthalein solution and observed for a red indication. All areas where the phenolphthalein was applied shall be rinsed with distilled water. Following the final electrolyte leakage test the battery shall be placed in a vacuum chamber for a minimum of 1 hour at a pressure of 1 Torr or less. If a positive indication of leakage is present during the second leakage test, the cell shall be rejected.

NOTE: 1. Before proceeding with this test perform failsafe circuit checks a, b, c of paragraph 3.3.5.2

4.5.3 Vibration.-

4.5.3.1 Vibration Test Inspection.-

a. Install the vibration assembly shop aid tool No. 106 or equivalent on the shaker head. Assembly orientation shall be such that the battery axes are in agreement with Figure 1.

b. Install the battery assembly 40-213827-01 on the vibration assembly and torque 6-32 bolts with flat washer to a torque of 5.5 in.-lb.

c. Install the monitor accelerometers adjacent to the x, y, and z axes and monitor the appropriate accelerometer for each axis test.

d. Install the battery electrical connector and prepare to monitor battery discharge voltage.

e. Initiate the battery discharge at the C/2 (1.5 $\pm$0.5 amperes) rate. The battery shall be discharged at least 5 minutes prior to vibration testing.

4.5.3.1.1 Random Vibration.- Apply the vibration level specified in Table IV, along the x, y, and z axes and record the output of the appropriate accelerometer. The battery shall be discharged at the C/2 rate (1.5 $\pm$0.05 amperes) during this test. The battery discharge voltage stability shall be monitored and recorded as shown in Paragraph 4.5.3.2.

4.5.3.1.2 Sinusoidal Vibration.- Apply the vibration level specified in Table III, along the x, y, and z axes and record the output of the appropriate accelerometer. The battery shall be discharged at the C/2 rate (1.5 $\pm$0.05 amperes) during this test. The battery discharge voltage stability shall be monitored and recorded as shown in Paragraph 4.5.3.2.

4.5.3.2 Discharge Voltage Stability.- The battery shall be fully charged before the initiation of the vibration test as specified in Paragraphs 3.2.10 and 3.2.11. During the test the battery discharge voltage shall maintain a stability of $\pm$0.25 volts over a one minute period when discharged at a C/2 rate (1.5 $\pm$0.05 amperes). The performance criteria shall apply to the first 20 minutes of discharge after a period of 5 minutes has elapsed. The measurement accuracy shall conform to the requirement specification Paragraph 3.3.4. See data sheets in Appendix A for detail test steps.

NOTE: If battery is not fully charged before initiation of vibration test, recondition discharge and recharge as specified in Para. 4.5.2.3 except maintain temperature at 24 $\pm 5^{\circ}$ C.

4.5.3.3 Visual Damage Inspection.- During and after the environmental testing of the battery, the battery shall be inspected for evidence of visible damage. Damage to the battery shall be any change in the assembly structure or components. The battery shall show no evidence of physical damage when subject to sinusoidal and random vibration testing as specified in Paragraph 4.5.3.1.

4.5.4 Post Vibration Performance.-

4.5.4.1 Capacity at 20°C.- The battery shall be subject to the electrical performance test delineated in Paragraph 4.5.2.3. The measurement accuracy shall be as specified in Paragraph 3.3.4. The battery shall deliver a minimum of 3.0 ampere hour capacity.

NOTE: 1. Before proceeding with this test perform failsafe circuit checks a, b, c, of paragraph 3.3.5.2.

4.5.4.2 Full Charge Voltage.- The battery shall be charged per paragraph 4.5.2.3 except at 24±5°C at the beginning of this test. With the battery mounted on a thermally controllable plate so that the temperature of the battery is stabilized at the test temperature 30±2°C and 10±2°C for a minimum period of 5.0 hours prior to the initiation of charge. The battery shall have been instrumented with thermocouples to determine thermal gradients within the battery. The battery shall then be subject to 4.0 ±0.5 hours of overcharge at the C/10 (0.3±0.015 ampere) rate at the 30°C test temperature and overcharged C/15 (0.2±0.015 ampere) rate for 4.0±0.5 hours at 10°C. The maximum allowable overcharge battery voltage shall be 29.6 volts or 1.48 volts per cell for the 30°C test. The respective voltage levels for the 10°C test shall be 30.8 volts and 1.54 volts. Measurement accuracy for these tests shall be in accordance with Paragraph 3.3.4.

4.5.4.3 Insulation Resistance.- Following the 20°C capacity measurement the battery shall be subject to an insulation resistance measurement in accordance with Paragraph 4.5.2.1. The measurement accuracy shall be ±0.1 megohms.

4.5.5 Thermal Vacuum.- Mount battery assembly in WDL's CVC PAS-41B thermal vacuum system.

4.5.5.1 Temperature Performance.- With the battery fully charged in a minimum vacuum of 1×10^{-5} Torr it shall be stabilized at each test temperature, 2°C, 20°C and 33°C ±2°C for a minimum period of 1.5 hours prior to discharge/charge cycling. The cycle begins with the battery being discharged at C/2 (1.5 ±0.05 amp) rate for 1.0 ±0.1 minutes and then charge at the C/10 (0.3 ±0.015 amp) rate for 10.0 ±1.0 minutes, except at 2°C where the charge rate shall be C/20 (0.15 ±0.01 amp). The minimum allowable discharge battery voltage shall be ≥24.0 volts at each of the three test temperatures. The measurement accuracy for these tests shall be in compliance with Paragraph 3.3.4. The battery shall be stabilized at each temperature for both the temperature performance test and the thermistor performance test according to Figure 3.

4.5.5.2 Thermistor Performance.- With the battery in a vacuum of 1×10^{-5} Torr, the battery temperature as determined by a calibrated thermocouple shall be stabilized at each test temperature, 2°C, 20°C, 33°C ±2°C for a minimum period of 5.0 hours. The resistance of the thermistor shall be within 2 percent of the required value shown in Table II, after 5 hours stabilization period. Measurement accuracy shall be ±25 ohms.

4.5.5.3 Thermal Vacuum Visual Inspection.- The battery shall be inspected for evidence of physical damage after completing thermal vacuum testing. The battery shall show no visible damage as delineated in Paragraph 4.5.3.3.

4.5.6 Post Thermal Vacuum Performance.-

4.5.6.1 Capacity at 20°C.- The battery shall be subject to the electrical performance test delineated in Paragraph 4.5.2.3. The measurement accuracy shall be as specified in Paragraph 3.3.4. The battery shall deliver a minimum of 3.0 ampere hour capacity.

NOTE: 1. Before proceeding with this test perform failsafe circuit checks a, b, c of Paragraph 3.3.5.2.

4.5.6.2 Pulse Load.- The battery shall be charged per Paragraph 4.5.2.3 except at 24±5°C, prior to the initiation of this test. With the battery stabilized at 24±5°C for 6.0 ±0.5 hours and then discharged C/2 (1.5A ±0.05A) for 0.2 ±0.02 hours, the battery shall be subjected to two pulse load conditions as follows:

a. Discharge at 25 ±0.5 amperes for a period of 10.0 ±2.0 seconds.

b. Discharge at 10.0 ±0.05 amperes for a period of 5.0 ±0.5 minutes.

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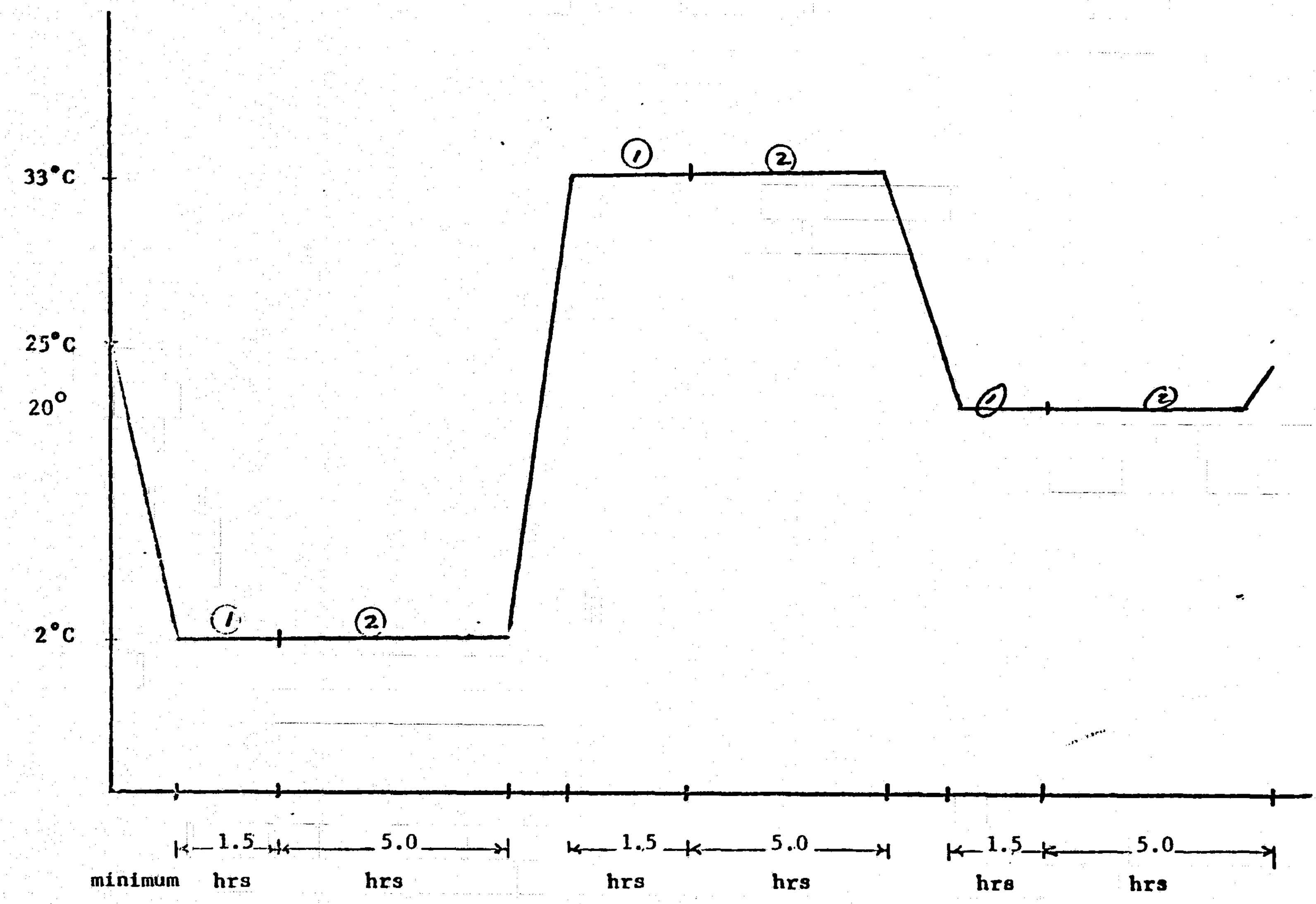
(1) Battery temperature performance test, see paragraph 4.5.5.1.

(2) Battery thermister performance test, see paragraph 4.5.5.2.



ELAPSED TIME OF EACH TEST

FIGURE 3

4.5.6.2 Pulse Load.- (continued)

NOTE: 1. Before proceeding with this test perform failsafe circuit checks a, b, c of Paragraph 3.3.5.2.

The period of time between these pulse discharge loads shall be at least 1.0 minute. The minimum allowable battery and cell discharge voltage shall be 18.5 and 0.70 volts respectively. The measurement accuracy shall meet the tolerances described in Paragraph 3.3.4.

4.5.6.3 Thermistor Performance.- The battery temperature shall be stabilized at each test temperature 2°C, 20°C and 33°C ±2°C for a minimum period of 5.0 hours as determined by a calibrated thermocouple. The resistance of the thermistor shall be within 2 percent of the required value shown in Table II, after the 5 hours stabilization period. Measurement accuracy shall be ±25 ohms.

4.5.6.4 Charge Retention.- This test shall be initiated with the battery cells discharged per Paragraph 4.5.2.3. Each cell shall be drained with a 1 ohm load for 16 ±0.5 hours at a temperature of 20 ±2°C. The cell shall then be placed on open circuit for a period of 24 ±0.5 hours at 20 ±2°C. The cell voltage at the end of this open circuit stand period shall be 1.16 volts minimum. The measurement accuracy of the test parameters shall be in accordance with Paragraph 3.3.4. The charge retention and electrolyte leakage detail test steps are in data sheet, Appendix A. Remove all instrumentation equipment for monitoring battery and cell voltages during the 24 hour open circuit stand period.

4.5.6.5 Insulation Resistance.- The insulation resistance of the battery shall be measured in accordance with Paragraph 4.5.2.1. This measurement shall follow the thermal vacuum tests described in Paragraph 4.5.6.6. The measurement accuracy shall meet the tolerance requirement of ±0.1 megohm.

4.5.6.6 Electrolyte Leakage.- The battery shall be subject to an electrolyte leakage measurement in accordance with Paragraph 4.5.2.7. The battery cell seals shall show no evidence of electrolyte leakage.

NOTE: 1. Before proceeding with this test perform failsafe circuit checks a, b, c of Paragraph 3.3.5.2.

5.0 PREPARATION FOR DELIVERY

5.1 Preservation, Packaging and Packing.- After completion of tests each battery shall be preserved within one week by performing the following:

a. Discharge each cell below 0.1 volt by placing a one ohm resistor across each cell for 16 hours minimum.

b. Remove the one ohm resistor and place a short across each cell.

c. Place each battery in a polyethylene bag and add an inert drying agent to exclude moisture. Heat seal each bag.

NOTE: Battery Assembly serial number shall be clearly visible from the outside of the bag.

d. Package each unit in a manner to avoid damage during shipment.

NOTE: For long term storage (periods in excess of two weeks) batteries shall be stored in a clean dry area at a temperature between 10 to 28°C.

5.2 Marking for Shipment and Storage.- All marking on shipping containers shall be clearly legible from a distance of 36 inches and may be applied by stencil, number stamp or lacquer over coated gummed labels.

The equipment furnished hereunder is for space flight use. All marking shall be blue in color and in addition, all shipping containers and shipping documents shall be marked as follows:

"ITEM FOR SPACE FLIGHT USE"

5.3 Electrical Cycling Instructions.- Each Battery Assembly shall be provided with one copy of the activation test procedure SC-227084 for Ford Aerospace use only.

6.0 NOTES

6.1 Definitions.-

6.1.1 Battery Capacity.- Battery capacity is the discharge measured quantitatively in ampere hours at the specified discharge rate to the specified cell cutoff voltage.

6.1.2 Cutoff Voltage.- The cutoff voltage of a cell is defined as that discharge voltage which represents the complete discharge condition of the cell for a particular rate. Discharge beyond this voltage would yield an insignificant amount of useful energy.

6.1.3 Reconditioning.- Depending on the use history of a battery, the responsible engineer may utilize the reconditioning procedure delineated in Paragraph 4.5.2.2 prior to any test.

APPENDIX A

7.0 TEST PROCEDURE DATA SHEETS

PRETEST VERIFICATION

Paragraph 3.3.5.1

			Initial Inspector		
PARA.	TEST	RESULTS	A	B	
A	30°C Shutoff	Chamber Off			
B	40°C Shutoff	Chamber/P.S. Off			
C	10°C Shutoff	Chamber & P.S. Off			
D	-7°C Shutoff	Chamber & P.S. Off			
E	Volt Sensor	"Out" Lights On			

TEST PROCEDURE DATA SUMMARY

Test/Paragraph	Requirement	Data	Date Test Operator QA Inspector
Examination of Product/ 4.5.1			
Workmanship/3.1.6	MIL-STD-454 Reqt. 9	______	______
Construction/3.1.7	SD-212066	______	______
Interchangeability 3.1.4	Dwg 213827	______	______
Weight/3.1.1	$\leq$ 7.9 lbs	______ lbs	______
Dimension/3.1	Dwgs 213827 & 211103	______	______
Functional Performance/ 4.5.2			
Insulation Resistance/ 4.5.2.1	$\geq$ 10 Mohms ±0.1Mohm at +100V (+10, -0)	______ MΩ	______
Reconditioning/4.5.2.2	$\geq$ 3.0 AH	______ AH	______
Capacity/4.5.2.3	$\geq$ 3.0 AH	______ AH	______
Low Temp Capacity/ 4.5.2.4	$\geq$ 2.25 AH	______ AH	______
High Temp Capacity/ 4.5.2.5	$\geq$ 1.50 AH	______ AH	______
Thermistor Performance/ 4.5.2.6 - ±2% of calibration curve value.	±2% @ +33°C	R_1 ______ Ω R_2 ______ Ω	______
	+20°C	R_1 ______ Ω R_2 ______ Ω	______
	+2°C	R_1 ______ Ω R_2 ______ Ω	______
Electrolyte Leakage/ 4.5.2.7	Colorless	______	______
Vibration/4.5.3			
Discharge Voltage Stability/4.5.3.2	±0.25V/min	______ V/min	______
Visual Inspection/ 4.5.3.3	No evidence	______	______
Post Vibration/4.5.4			
Capacity/4.5.4.1	$\geq$ 3.0 AH	______ AH	______
Full Charge Voltage/ 4.5.4.2	30°C, 29.6V/ Battery	______ V/Batt.	______
	$\leq$ 1.48V/Cell	______ V/Cell	______
	10°C, $\leq$ 30.8V/ Battery	______ V/Batt.	______
	$\leq$ 1.54V/Cell	______ V/Cell	______

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TEST PROCEDURE DATA SUMMARY (Continued)

Test/Paragraph	Requirement	Data	Date Test Operator QA Inspector
Insulation Resistance/ 4.5.4.3	≥10 Mohms ±0.1Mohm at +100V	____ MΩ	____ ____ ____
Thermal Vacuum/4.5.5			
Temperature Performance/ 4.5.5.1	≥24.0V at +33°C	____ V	____
	≥24.0V at +20°C	____ V	____
	≥24.0V at +2°C	____ V	____
Thermistor Performance/ 4.5.5.2	±2% of Calibration curve value.	R1 R2	
		33°C ____ ____ Ω	____
		20°C ____ ____ Ω	____
		2°C ____ ____ Ω	____
Visual Inspection/ 4.5.5.3	No evidence	____	
Post Thermal-Vacuum/4.5.6			
Capacity/4.5.6.1	≥3.0 AH	____ AH	____
Pulse Load/4.5.6.2	18.5 V/Batt.	____ V	____
	0.7V/Cell		
	Max.	____ V	____
	Min.	____ V	____
Thermistor Performance/ 4.5.6.3	±2% of Calibration curve value	R1 R2	
		33°C ____ ____ Ω	____
		20°C ____ ____ Ω	____
		2°C ____ ____ Ω	____
Charge Retention/4.5.6.4	1.16V/Cell		
	Max.	____ V	____
	Min.	____ V	____
Insulation Resistance/ 4.5.6.5	≥10 Mohms ±0.1Mohm at +100V	____ MΩ	____ ____ ____ ____ ____
Electrolyte Leakage/ 4.5.6.6	Colorless	____	____

SMS Battery Assembly Part No. 40-213827-01 Battery Assembly Serial No. 100X.

DATA REVIEWERS

Engineering ____________

Quality Assurance ____________

GSI ____________

INSULATION RESISTANCE

4.5.2.1

CELL POSITION	CELL S/N	CELL POSITION	CELL S/N
19	___	20	___
17	___	18	___
15	___	16	___
13	___	14	___
11	___	12	___
9	___	10	___
7	___	8	___
5	___	6	___
3	___	4	___
1	___	2	___

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INSULATION RESISTANCE TEST DATA

SMS BATTERY S/N ______

TEST PROCEDURE ____________ PARA 4.5.2.1 DATE ____________

TEST CONDUCTOR ____________ INSPECTOR ____________

REQUIRED MINIMUM RESISTANCE: 10 MEG OHMS

MEASURE RESISTANCE at 100 VOLTS

	PIN	TO	PIN	
I.	32		1-31, 33-37	______ MΩ
II.	32		CELL 1-20 CASE	______ MΩ
III.	13, 14, 15, 16		1-12, 17-37	______ MΩ

RECONDITIONING

4.5.2.2

CELL POSITION	CELL S/N	CELL POSITION	CELL S/N
19	____	20	____
17	____	18	____
15	____	16	____
13	____	14	____
11	____	12	____
9	____	10	____
7	____	8	____
5	____	6	____
3	____	4	____
1	____	2	____

Verification of failsafe circuit tests per Paragraph 3.3.5.2.

Test Conductor ______________________

Inspector __________________________

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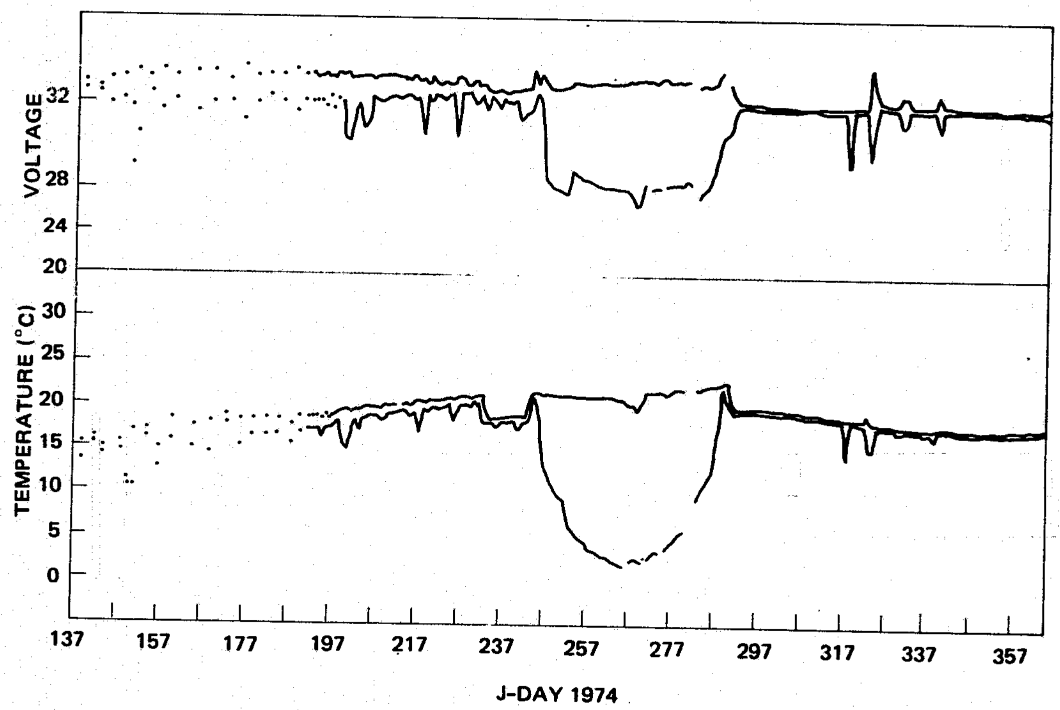
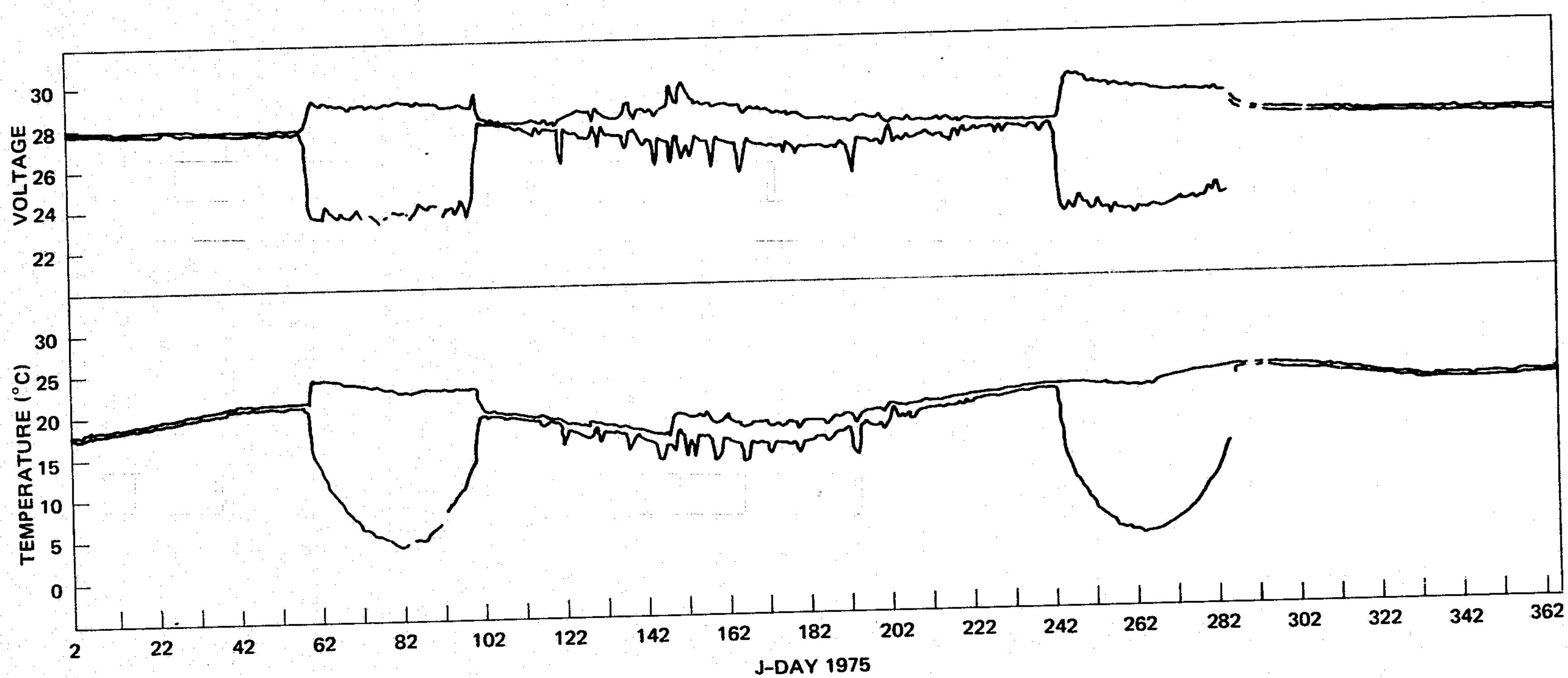
APPENDIX N

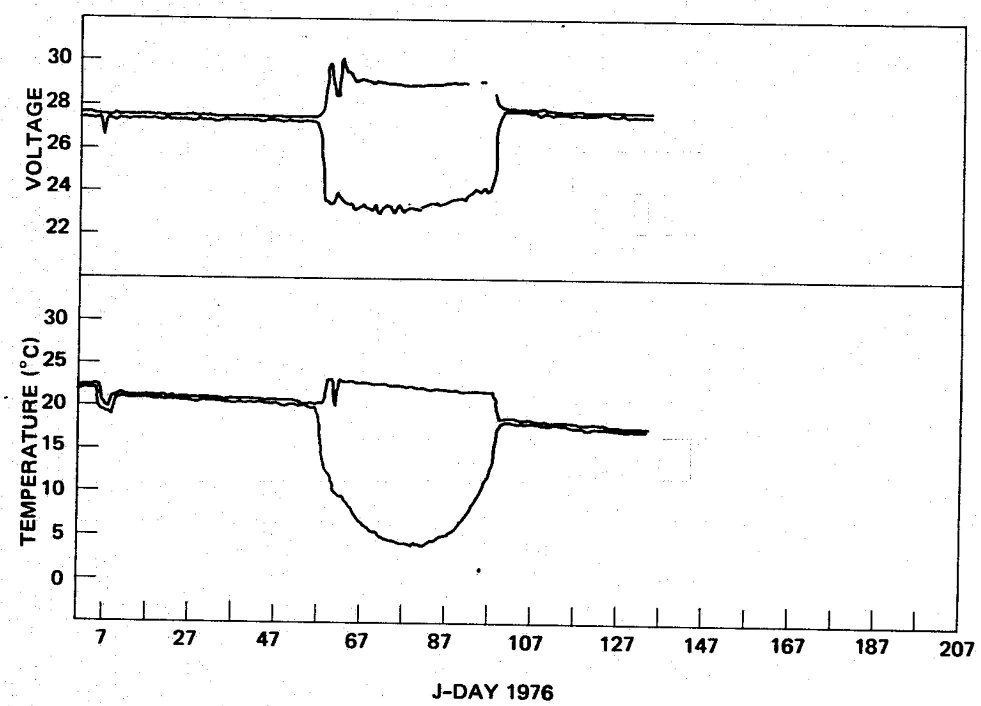
NOAA AND NWSC/CRANE DATA



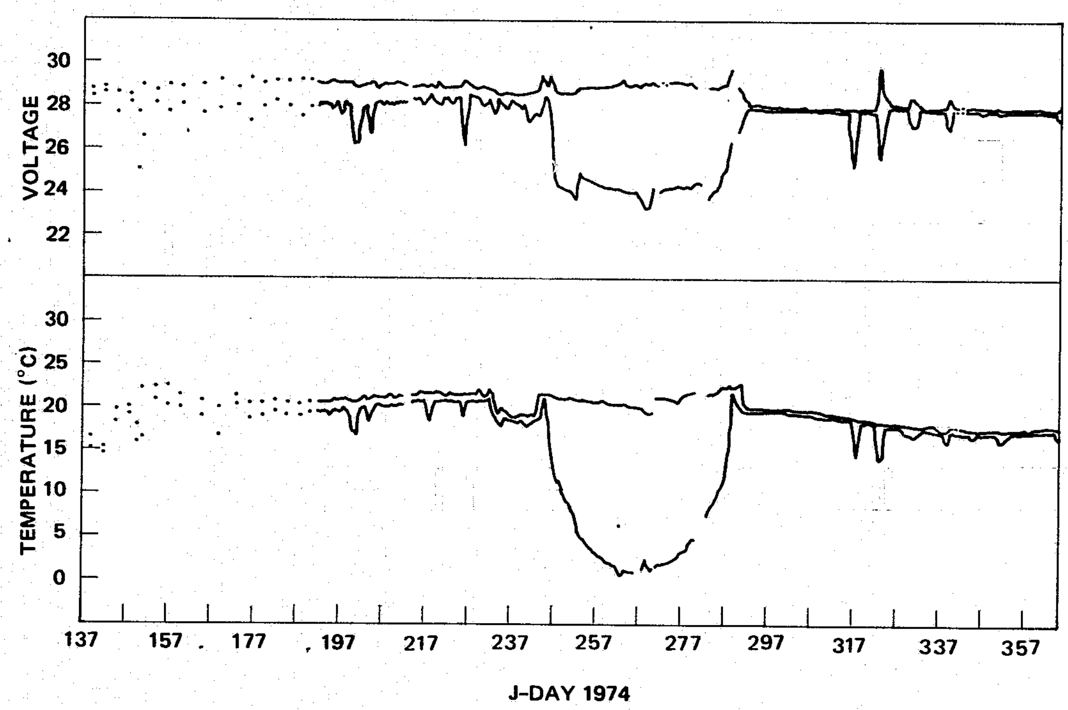
SMS-A Autumnal Eclipse Season for 1974, Battery 1 (S/N 1006), Temperature and Voltage



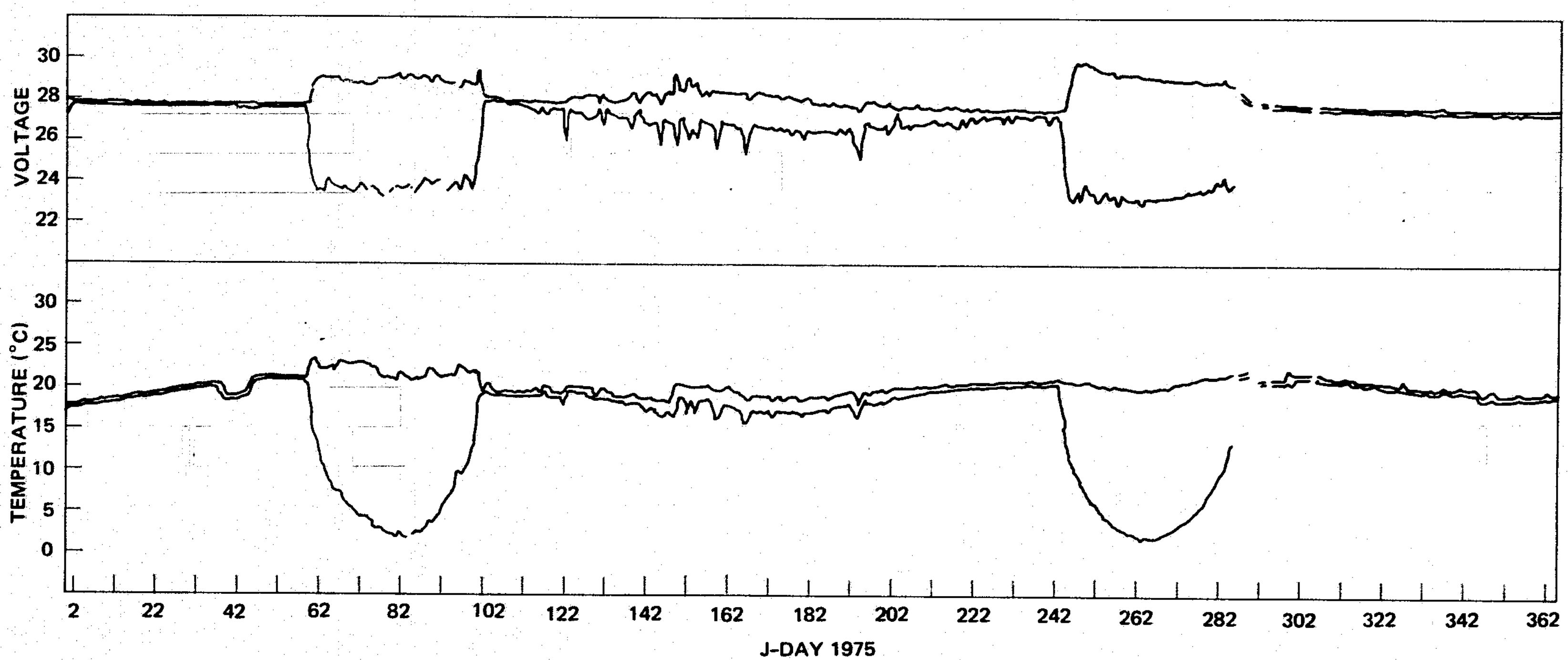
SMS-A Vernal and Autumnal Eclipse Seasons for 1975, Battery 1 (S/N 1006), Temperature and Voltage



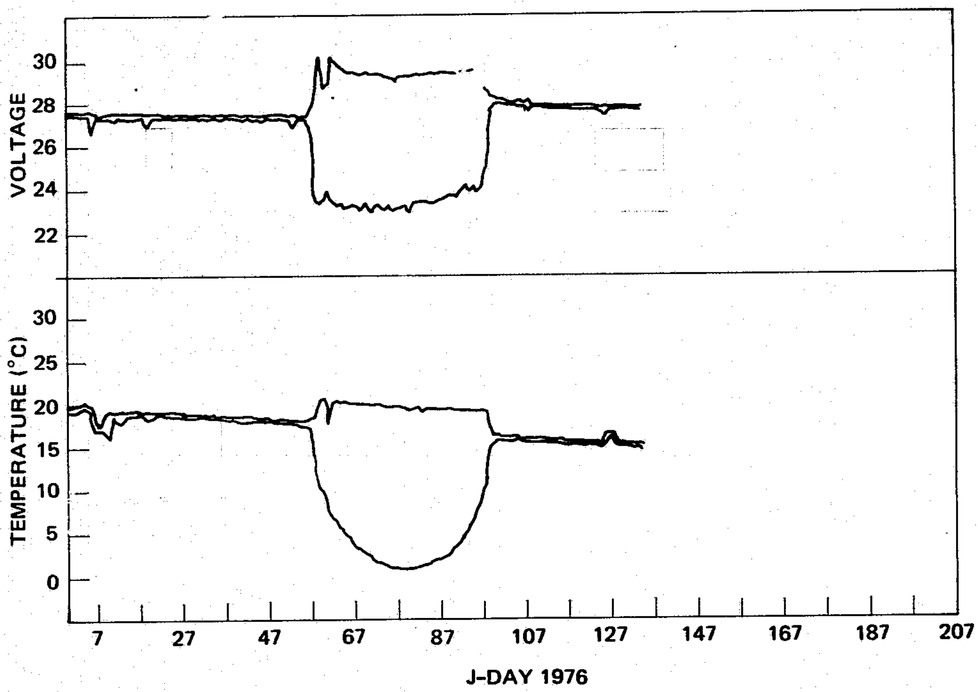
SMS-A Vernal Eclipse Season for 1976, Battery 1 (S/N 1006), Temperature and Voltage



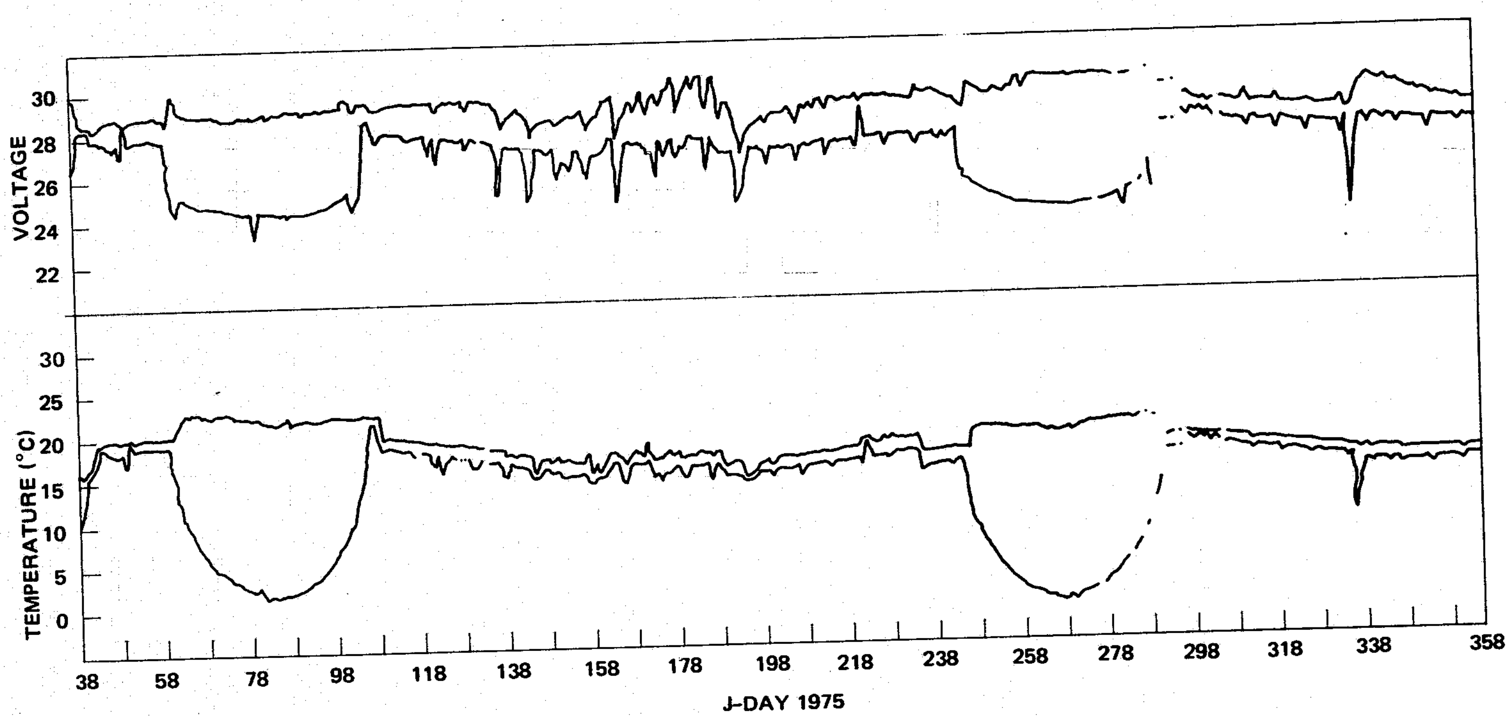
SMS-A Autumnal Eclipse Season for 1974, Battery 2 (S/N 1007), Temperature and Voltage



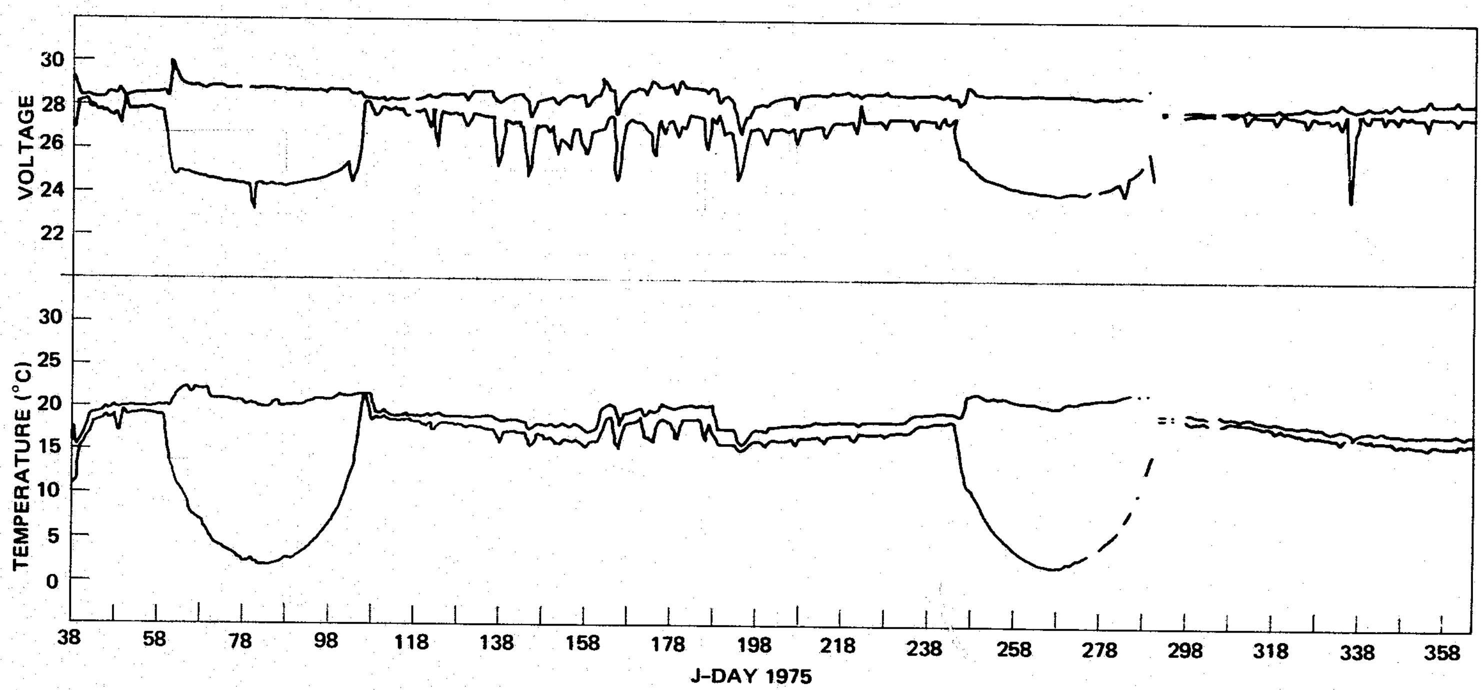
SMS-A Vernal and Autumnal Eclipse Seasons for 1975, Battery 2 (S/N 1007), Temperature and Voltage



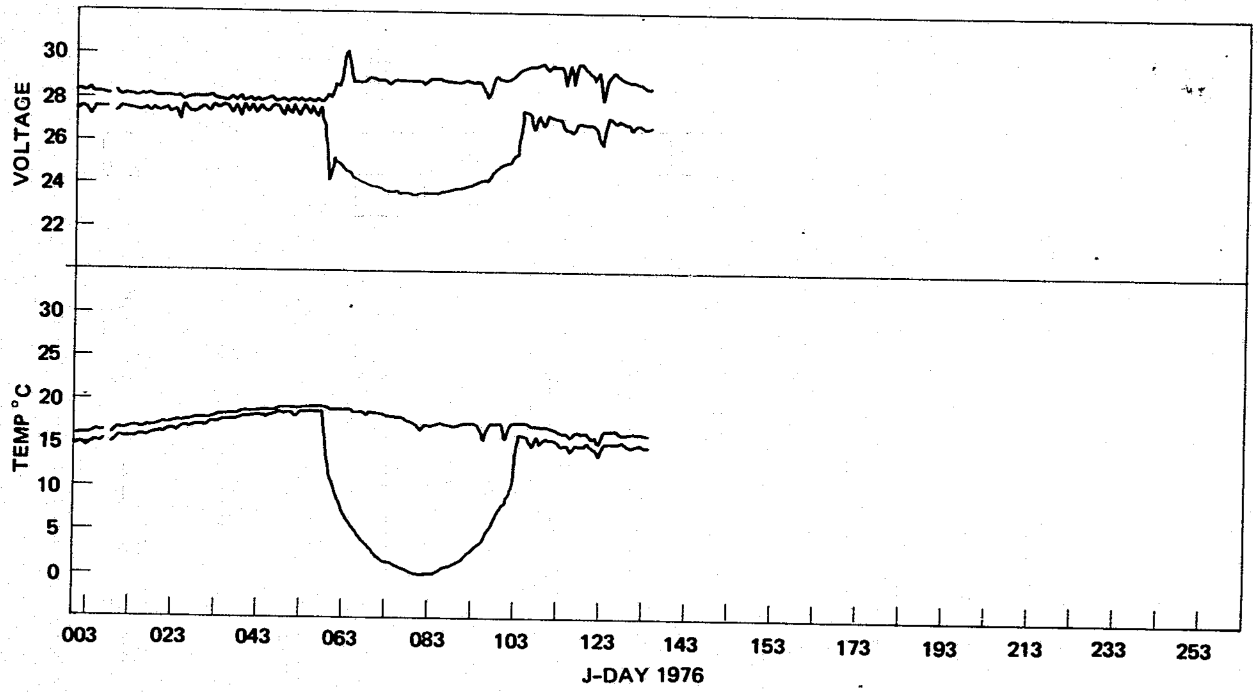
SMS-A Vernal Eclipse Season for 1976, Battery 2 (S/N 1007), Temperature and Voltage



SMS-B Vernal and Autumnal Eclipse Seasons for 1975, Battery 1 (S/N 1008), Temperature and Voltage



SMS-B Vernal and Autumnal Eclipse Seasons for 1975, Battery 2 (S/N 1009), Temperature and Voltage



SMS-B Vernal Eclipse Season for 1976, Battery 1 (S/N 1008), Temperature and Voltage

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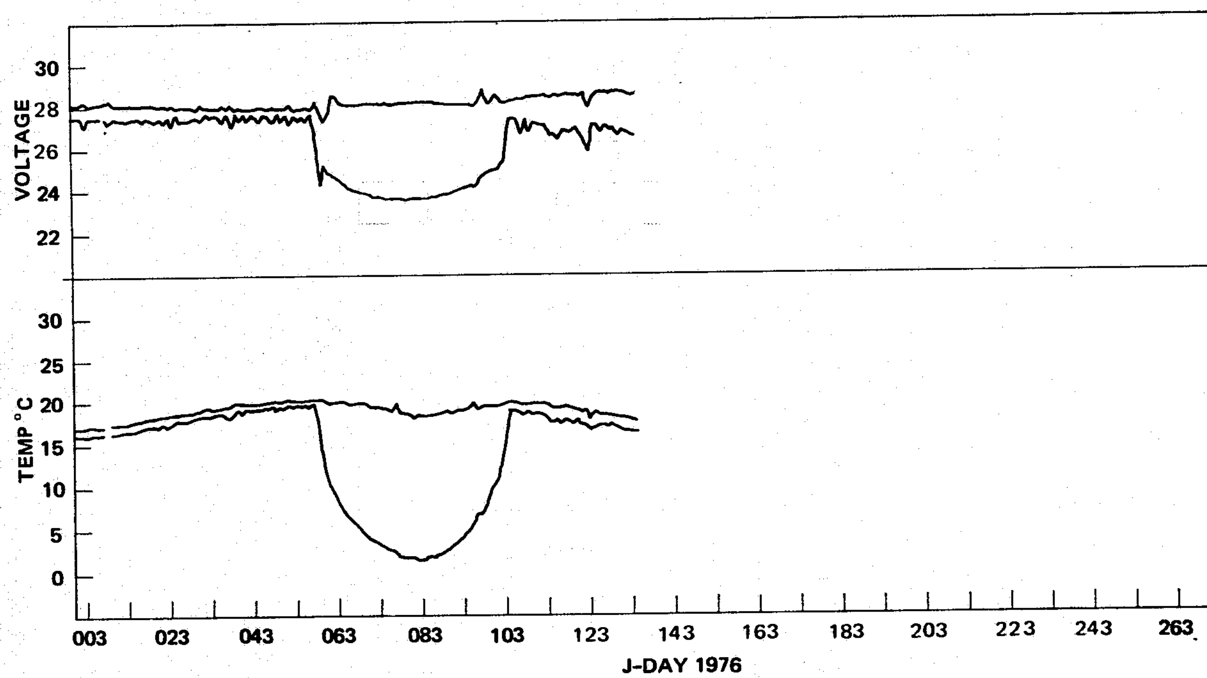
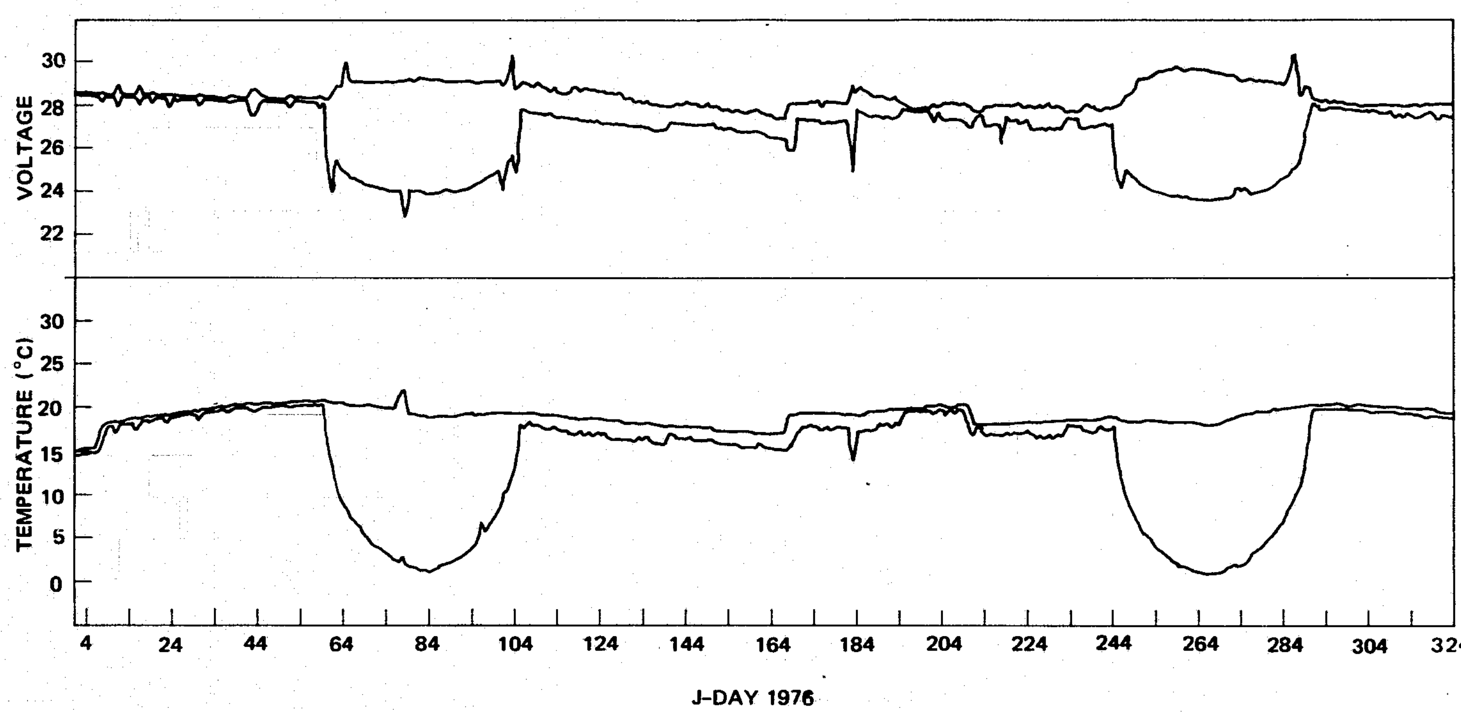
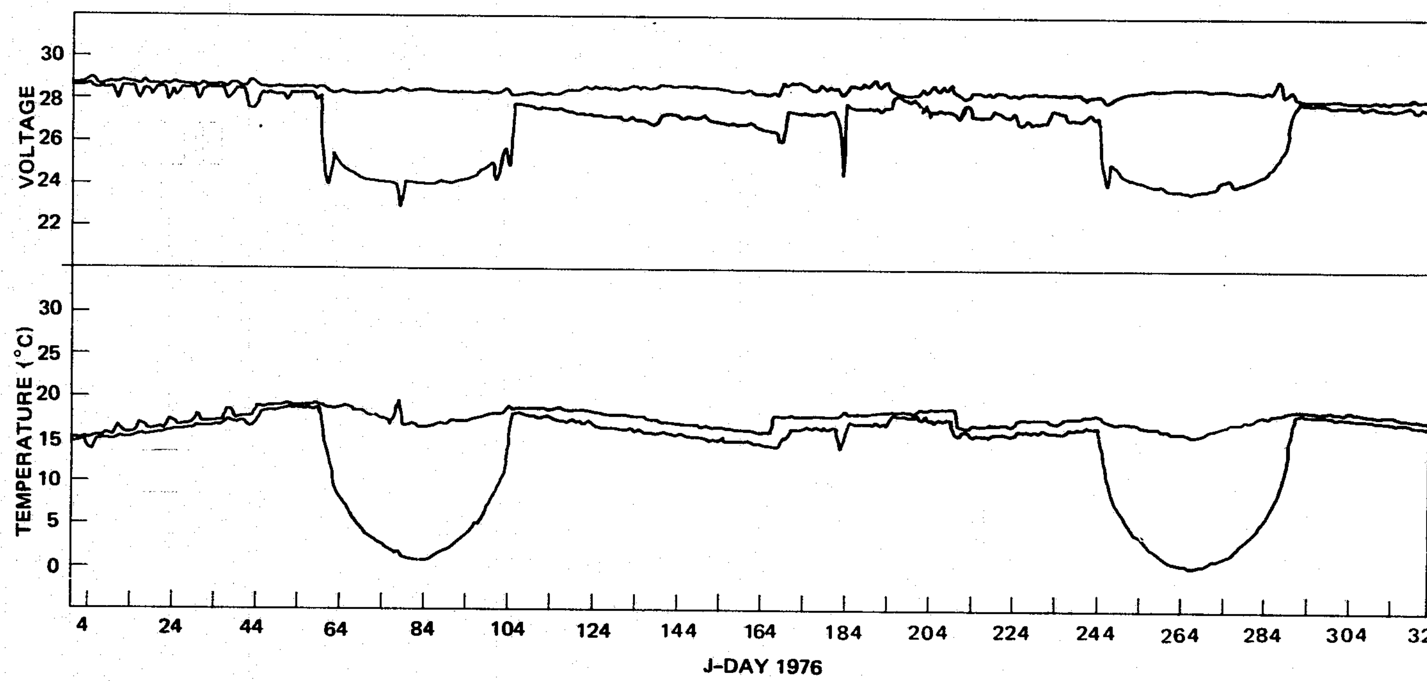


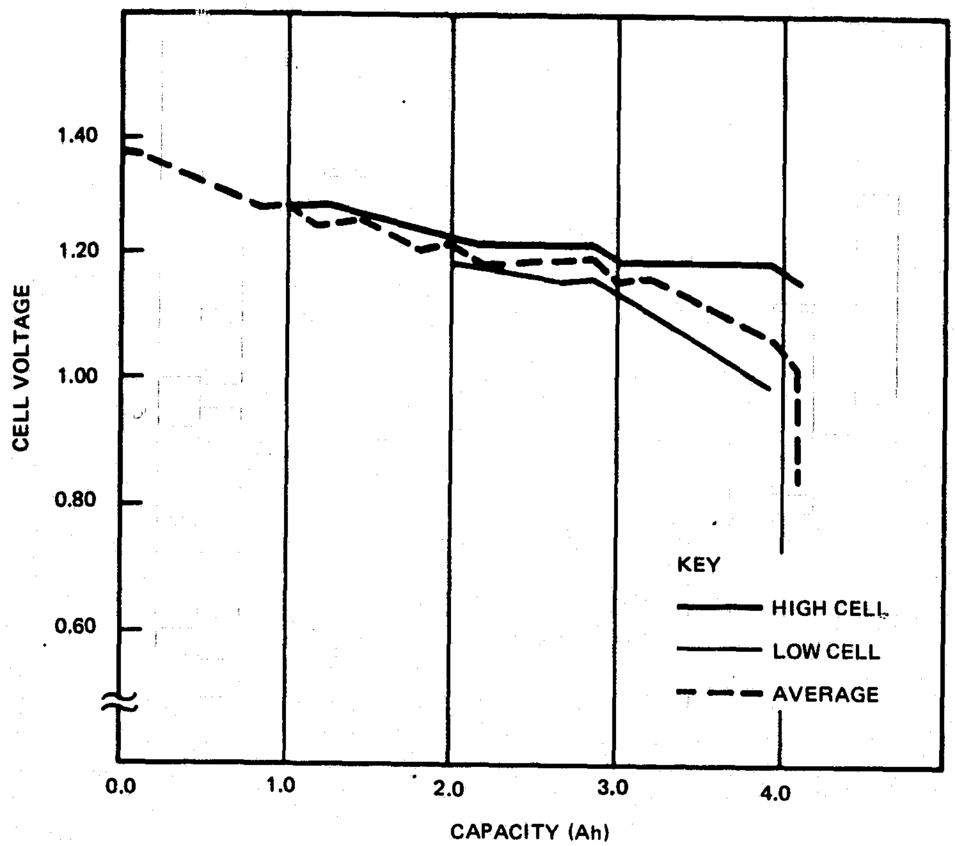
SMS-B Vernal Eclipse Season for 1976, Battery 2 (S/N 1009), Temperature and Voltage



GOES-A Vernal and Autumnal Eclipse Seasons for 1976, Battery 1 (S/N 1005), Temperature and Voltage



GOES-A Vernal and Autumnal Eclipse Seasons for 1976, Battery 2 (S/N 1012), Temperature and Voltage



Pack 227B, Pre-Shadow, Cycle 18, C/2 Discharge Characteristics

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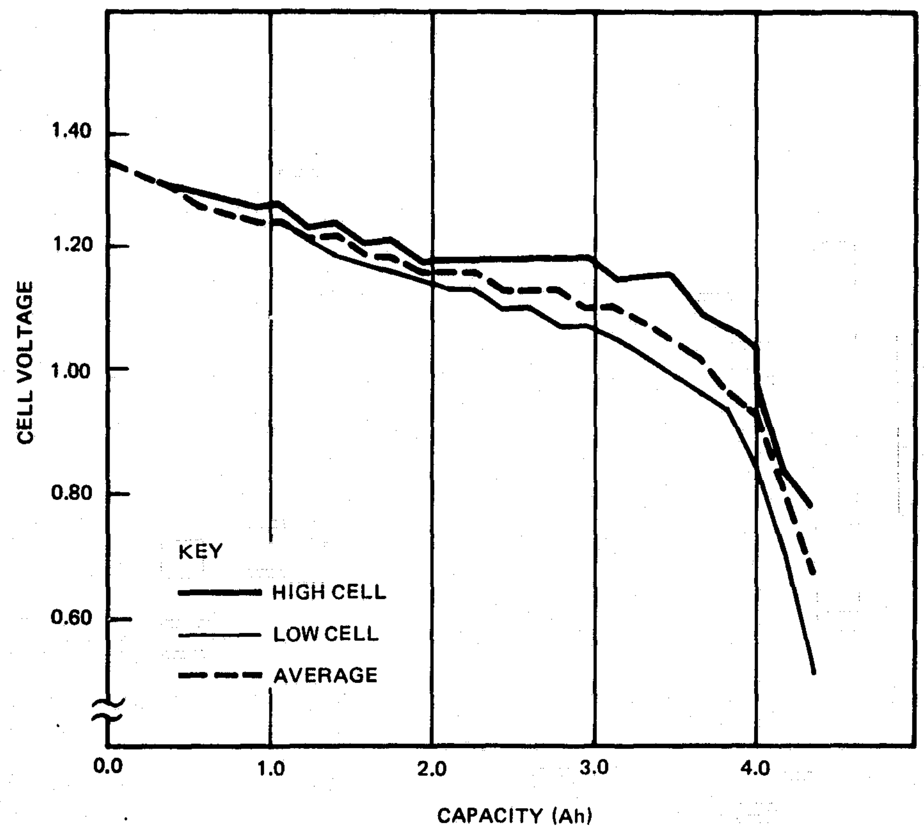
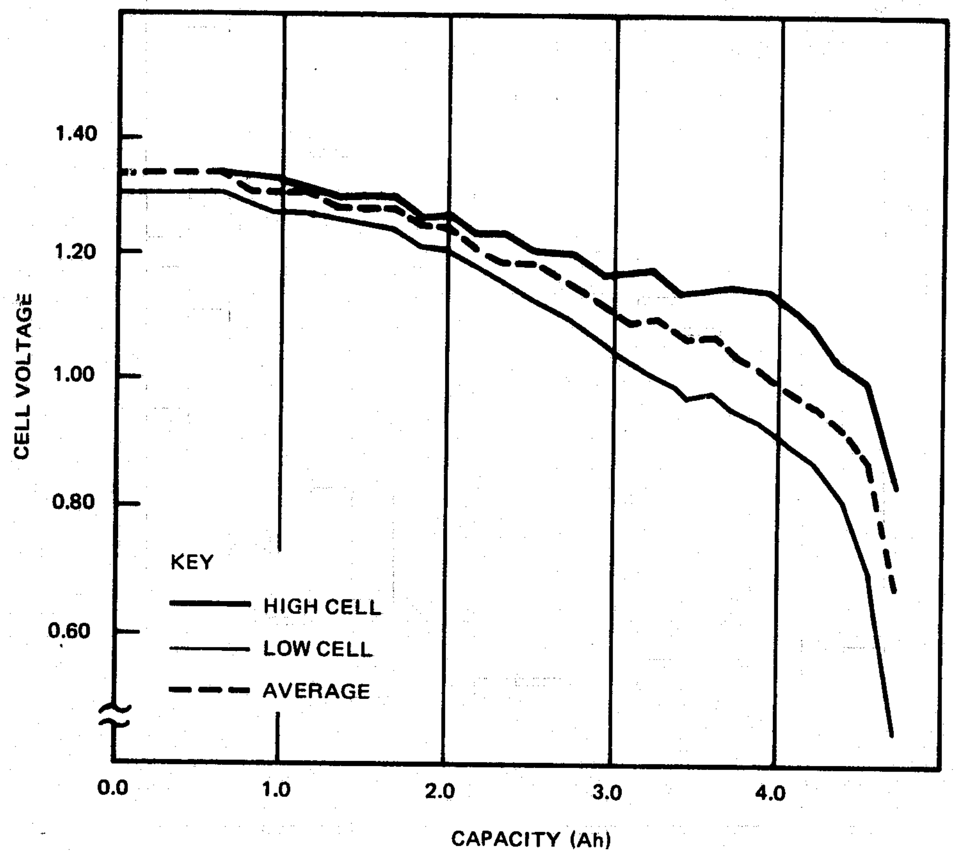


Pack 227B, Shadow Period 2, Cycle 296, C/2 Discharge Characteristics



Pack 227B, Shadow Period 3, Cycle 557, C/2 Discharge Characteristics

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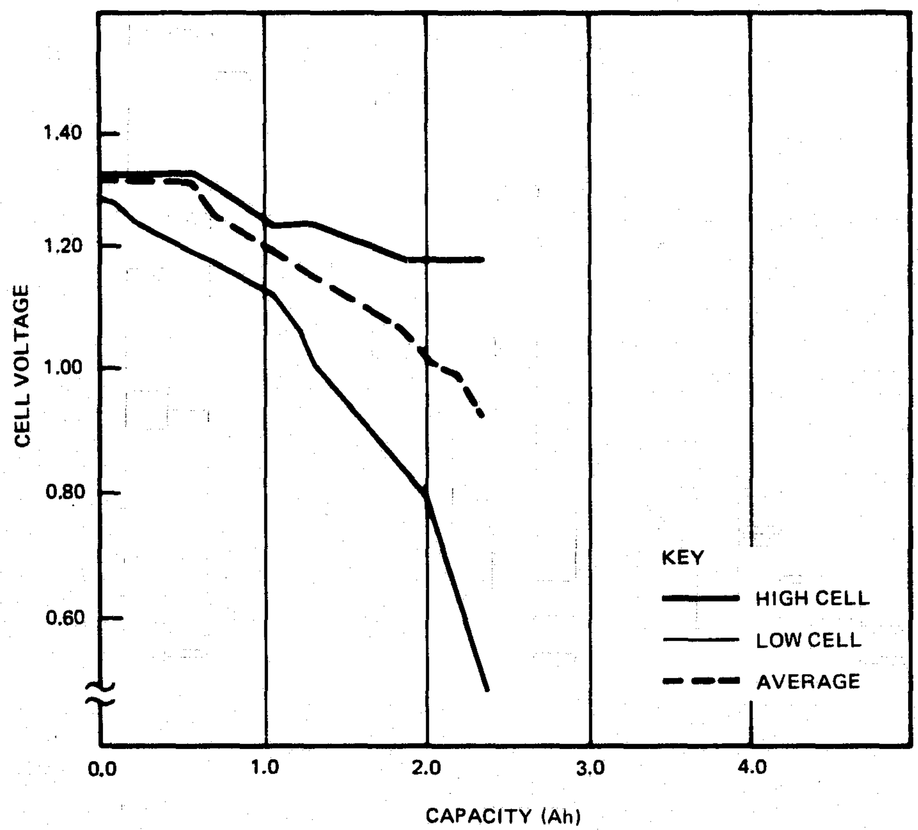
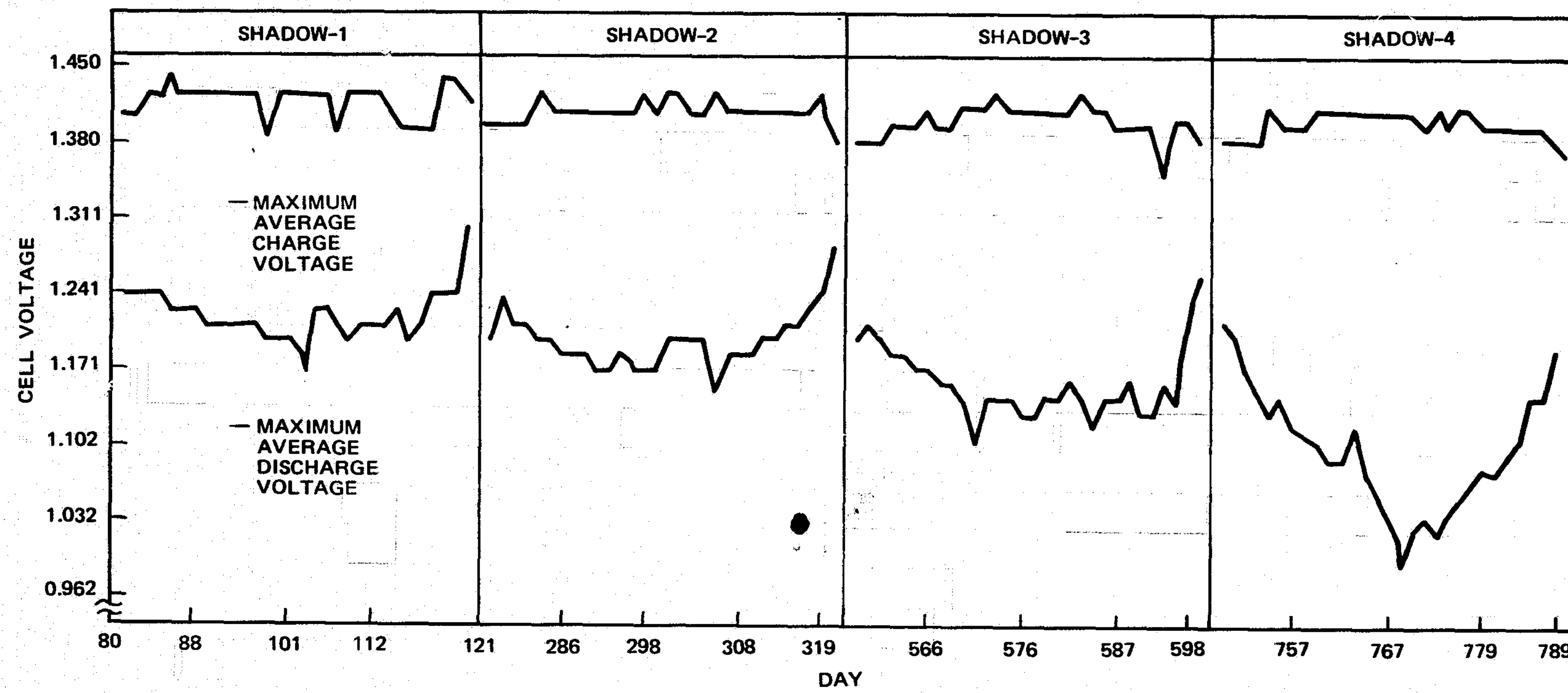
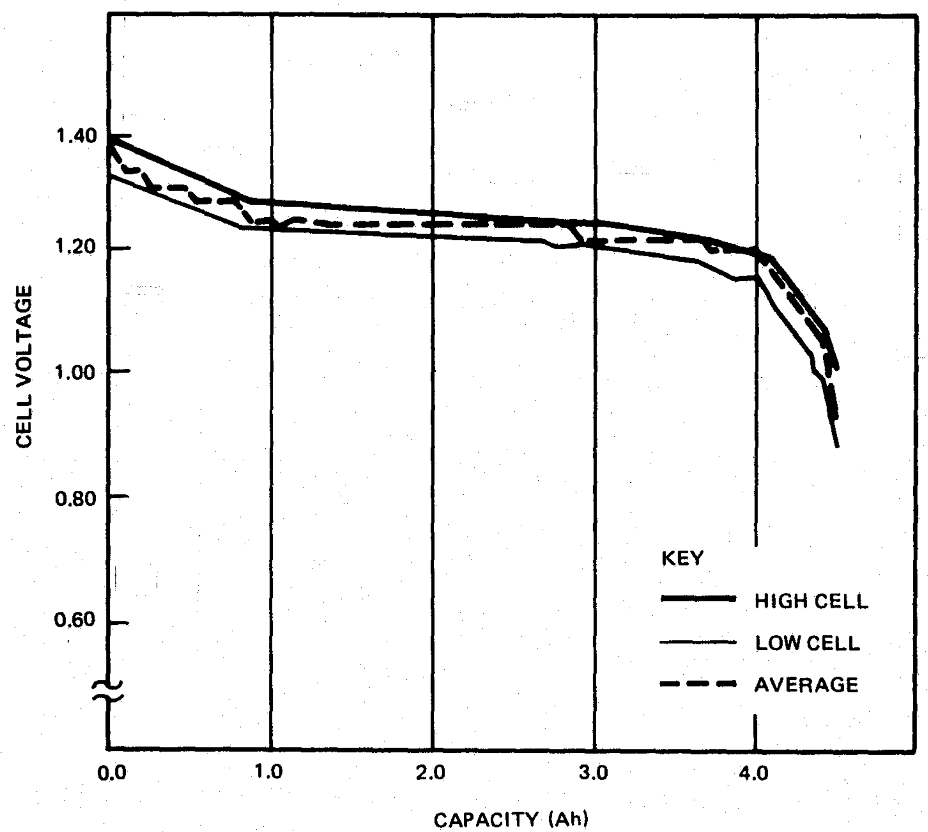


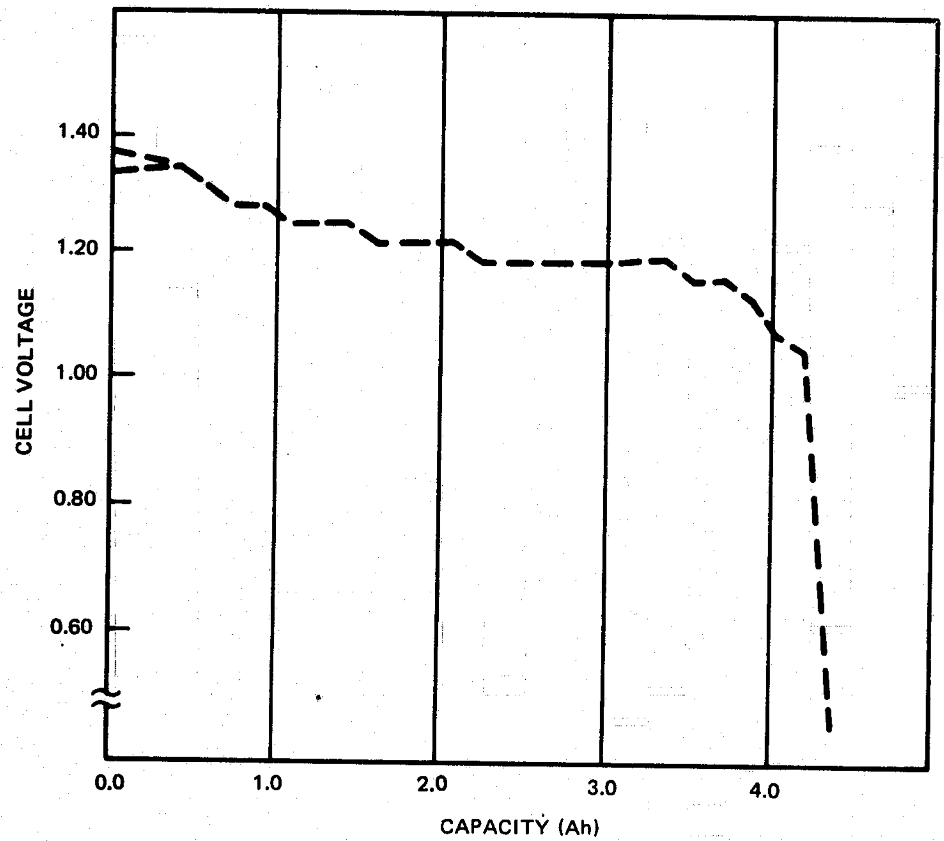
Pack 227B, Shadow Period 4, Cycle 768, C/2 Discharge Characteristics



Pack 227B, Shadow Periods 1 through 4, Minimum/Maximum Average Cell Voltage Characteristics



Pack 227C, Pre-Cycle Discharge Characteristics



Pack 227C, Shadow Period 1, Cycle 36, Average C/2
Discharge Characteristics

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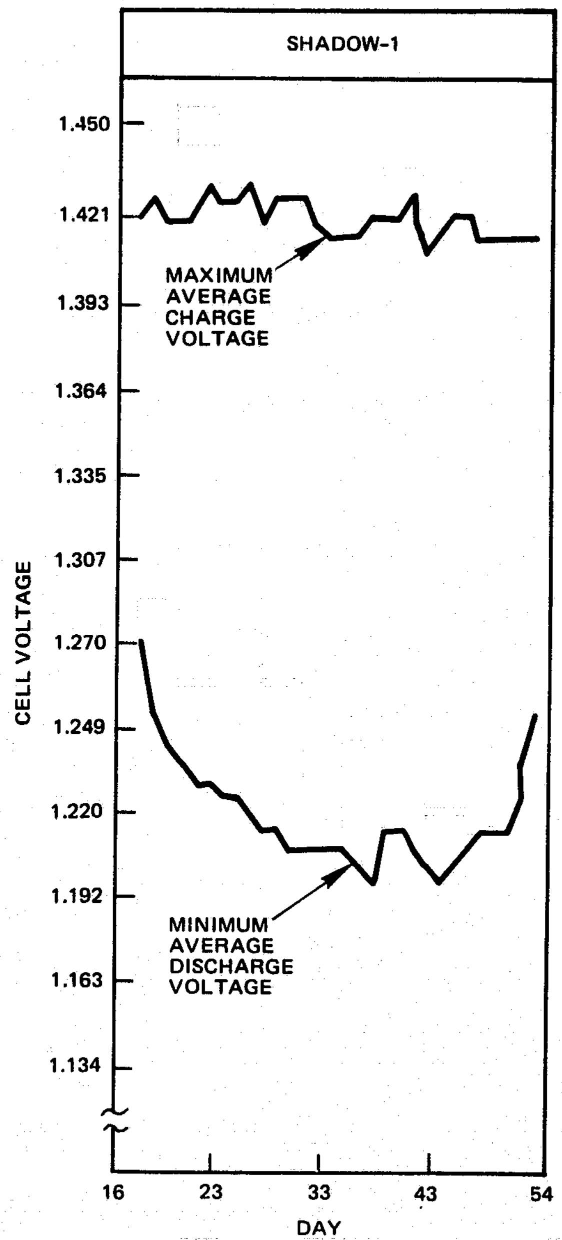

Pack 227C, Shadow Period 1, Minimum/Maximum Average Cell Voltage Characteristics

APPENDIX O

SMS/GOES BATTERY CELL LOAD-SHARING TEST DATA

BATTERY CELL LOAD SHARING TEST

Test Articles - Lot 10 & 12 Cells S/N 745, 750, 755, 759, 762 772, 776, 790, 808, 816, 817, 902, 923, 925, 927, 941, 944, 977, 979, 981

Test Sequence	Start Date	Test No.
Reconditioning Per Para 4.5.2.7 (SC-213728B)		
C/20 Charge for 40 hours @ 22°C	(11/3/76)	1
C/2 Discharge, one ohm 4 hours	(11/5/76)	2
C/10 Charge for 16 hours @ 22°C	(11/8/76)	3
C/2 Discharge, one ohm 16 hours	(11/9/76)	4
Capacity Per Para 4.5.2.4 (SC-213728B)		
C/10 Charge for 20 hours @ 20°C	(11/10/76)	5
C/2 Discharge, one ohm 16 hours	(11/11/76)	6
Special Engineering Tests		
C/10 Charge for 20 hours @ 20°C	(11/15/76)	7
Load sharing for 92% efficiency @ 10°C	(11/23/76	8
106mA Charge for 410ms (168hrs) 200mA Discharge for 200 ms		
C/2 Discharge @ 10°C	(11/30/76)	9
C/20 Charge for 40 hours @ 10°C	(11/30/76)	10
C/2 Discharge, one ohm 6 days	(12/2/76)	11
Open circuit storage 34 days	(12/8/76)	12
C/20 Charge for 40 hours @ 24°C	(01/11/77)	13
C/2 Discharge, one ohm 4 hours	(01/13/77)	14
C/10 Charge for 16 hours @ 24°C	(01/13/77)	15
C/2 Discharge @ 24°C	(01/14/77)	16
C/10 Charge for 20 hours @ 20°C	(01/14/77)	17
C/2 Discharge @ 20°C	(01/15/77)	18
C/10 Charge for 20 hours @ 20°C	(01/15/77)	19
Open circuit storage one day	(01/16/77)	20
C/2 Discharge @ 10°C	(01/17/77)	21
C/20 Charge for 40 hours @ 10°C	(01/17/77)	22
C/2 Discharge @ 10°C	(01/19/77)	23
C/10 Charge for 20 hours @ 25°C	(01/19/77)	24
C/2 Discharge @ 25°C	(01/20/77)	25
Open circuit storage 1 day	(01/21/77)	26
Load sharing for 92% efficiency @ 25°C	(01/22/77)	27
120mA charge for 500ms (91hrs) 540mA discharge for 102ms		
C/2 Discharge @ 25°C	(01/26/77)	28
C/20 Charge for 20 hours @ 25°C	(01/26/77)	29
C/2 Discharge @ 25°C	(01/27/77)	30
C/10 Charge for 20 hours @ 25°C	(01/27/77)	31

ORBITAL LOAD SHARING TEST*

Cells S/N 745, 750, 755, 759, 776, 808, 817
902, 923, 941, 944, 979

Load Sharing for 86% efficiency @ 26°C (01/28/77)

120mA Charge for 500ms
516mA Discharge for 100ms (14 weeks)

*The following eleven cells were discharged with matrix load sharing test on indicated dates.

Cell S/N	Dates
745	(02/02/77 to 02/04/77)
902	(02/09/77 to 02/11/77)
750	(02/16/77 to 02/18/77)
923	(02/23/77 to 02/25/77)
755	(03/02/77 to 03/04/77)
941	(03/09/77 to 03/11/77)
759	(03/16/77 to 03/18/77)
944	(03/23/77 to 03/27/77)
776	(04/01/77 to 04/06/77)
979	(04/11/77 to 04/13/77)
808	(04/19/77 to 04/21/77)
817	(04/26/77 to 04/28/77)

All cells discharged on 05/05/77, recharged and calibration discharged on 05/06/77 at 27°C, followed by reconditioning and 20°C capacity discharge on 05/10/77.

MATRIX LOAD SHARING TEST

Cells S/N 403, 511, 596, 762, 772, 790, 816, 925, 927, 977, 981

		Test No.
Load sharing for 82% efficiency @ 25°C	(01/28/77)	32
118mA Charge for 500ms 485mA Discharge for 100ms (120hrs)		
C/2 Discharge @ 25°C	(02/02/77)	33
C/10 Charge for 20 hours @ 25°C	(02/02/77)	34
C/2 Discharge @ 25°C	(02/03/77)	35
C/10 Charge for 20 hours @ 25°C	(02/04/77)	36
Load sharing for 90% efficiency @ 25°C	(02/04/77)	37
140mA Charge for 500ms 630mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 25°C	(02/09/77)	38
C/10 Charge for 20 hours @ 25°C	(02/09/77)	39
C/2 Discharge @ 25°C	(02/10/77)	40
C/10 Charge for 20 hours @ 25°C	(02/11/77)	41
Load sharing for 80% efficiency @ 25°C	(02/11/77)	42
140mA Charge for 500ms 560mA Discharge for 100ms (96hrs)		
C/2 Discharge @ 25°C	(02/16/77)	43
C/10 Charge for 20 hours @ 25°C	(02/16/77)	44
C/2 Discharge @ 25°C	(02/17/77)	45
C/10 Charge for 20 hours @ 25°C	(02/17/77)	46

MATRIX LOAD SHARING TEST		Test No.
Load Sharing for 90% efficiency @ 26°C	(02/18/77)	47
210mA Charge for 500ms 945mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 26°C	(02/23/77)	48
C/10 Charge for 20 hours @ 26°C	(02/23/77)	49
C/2 Discharge @ 26°C	(02/24/77)	50
C/10 Charge for 20 hours @ 26°C	(02/24/77)	51
Load sharing for 80% efficiency @ 26°C	(02/25/77)	52
210mA Charge for 500ms 840mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 26°C	(03/02/77)	53
C/10 Charge for 20 hours @ 26°C	(03/02/77)	54
C/2 Discharge @ 26°C	(03/03/77)	55
C/10 Charge for 20 hours @ 26°C	(03/03/77)	56
Load sharing for 99% efficiency @ 26°C	(03/04/77)	57
210mA Charge for 500ms 1,030mA Discharge for 100ms (118hrs)		58
C/2 Discharge @ 26°C	(03/09/77)	58
C/10 Charge for 20 hours @ 26°C	(03/09/77)	59
C/2 Discharge @ 26°C	(03/10/77)	60
C/10 Charge for 20 hours @ 26°C	(03/10/77)	61
Load sharing for 108% efficiency @ 26°C	(03/11/77)	62
71mA Charge for 500ms 383mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 26°C	(03/16/77)	63
C/10 Charge for 20 hours @ 26°C	(03/16/77)	64
C/2 Discharge @ 26°C	(03/17/77)	65
C/10 Charge for 20 hours @ 26°C	(03/17/77)	66
Load sharing for 90% efficiency @ 10°C	(03/18/77)	67
210mA Charge for 500ms 945mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 10°C	(03/23/77)	68
C/20 Charge for 40 hours @ 10°C	(03/23/77)	69
C/2 Discharge @ 10°C	(03/25/77)	70
C/20 Charge for 40 hours @ 10°C	(03/25/77)	71
Load sharing for 80% efficiency @ 10°C	(03/27/77)	72
210mA Charge for 500ms 840mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 10°C	(04/01/77)	73
C/20 Charge for 40 hours @ 10°C	(04/01/77)	74
C/2 Discharge @ 10°C	(04/03/77)	75
C/20 Charge for 40 hours @ 10°C	(04/05/77)	76

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MATRIX LOAD SHARING TEST

		Test No.
Load sharing for 60% efficiency @ 10°C	(04/06/77)	77
210mA Charge for 500ms 630mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 10°C	(04/11/77)	78
C/20 Charge for 40 hours @ 10°C	(04/11/77)	79
C/2 Discharge @ 10°C	(04/13/77)	80
C/10 Charge for 20 hours @ 20°C	(04/13/77)	81
Load sharing for 90% efficiency @ 20°C	(04/14/77)	82
210mA Charge for 500ms 945mA Discharge for 100ms (110hrs)		
C/2 Discharge @ 20°C	(04/19/77)	83
C/10 Charge for 20 hours @ 20°C	(04/19/77)	84
C/2 Discharge @ 20°C	(04/20/77)	85
C/10 Charge for 20 hours @ 20°C	(04/20/77)	86
Load sharing for 60% efficiency @ 20°C	(04/21/77)	87
210mA Charge for 500ms 630mA Discharge for 100ms (118hrs)		
C/2 Discharge @ 20°C	(04/26/77)	88
C/10 Charge for 20 hours @ 20°C	(04/26/77)	89
C/2 Discharge @ 20°C	(04/27/77)	90
C/10 Charge for 20 hours @ 20°C	(04/27/77)	91
Load sharing for 93% efficiency @ 27°C	(04/28/77)	92
71mA Charge for 500ms 330mA Discharge for 100ms (154hrs)*		
C/2 Discharge @ 27°C	(05/05/77)	93
C/10 Charge for 20 hours @ 27°C	(05/05/77)	94
C/2 Discharge @ 25°C, one ohm 16 hours	(05/06/77)	95
C/10 Charge for 20 hours @ 20°C	(05/09/77)	96
C/2 Discharge @ 20°C, one ohm for storage	(05/10/77)	97

*Cells on Open Circuit for 16 Hours after 102 Hours Elapsed Charge Time. Charging was then resumed for 52 Hours resulting in 154 Hours total charge time.

RECONDITIONING AND SPECIAL ENGINEERING TESTS

TEST NO.		2	4	6	9	11	14	16	19	21	23
CELL POSITION	CELL S/N	RECONDITION INITIAL DISCHARGE (11/05/76)	RECONDITION 2nd CYCLE (11/09/76)	CALIBRATION CAPACITY CYCLE (11/11/76)	CAPACITY AFTER CYCLING (11/30/76)	CALIBRATION CAPACITY CYCLE (12/02/76)	RECONDITION INITIAL DISCHARGE (01/13/77)	RECONDITION 2nd CYCLE (01/14/77)	CALIBRATION CAPACITY CYCLE (01/15/77)	CAPACITY AFTER 1 DAY O.C. (1/17/77)	CALIBRATION CAPACITY CYCLE (01/19/77)
1	745	4.20 (1.439)	4.05 (1.443)	4.14 (1.516)	3.83 (1.404)	3.95 (1.464)	4.32 (1.452)	3.96 (1.425)	4.35 (1.469)	3.69	3.96 (1.460)
2	750	4.28 (1.466)	3.87 (1.428)	4.23 (1.527)	3.80 (1.400)	4.02 (1.469)	4.28 (1.446)	3.93 (1.424)	4.40 (1.472)	3.68	3.96 (1.458)
3	755	4.32 (1.468)	3.93 (1.430)	4.26 (1.532)	3.80 (1.400)	3.99 (1.473)	4.31 (1.451)	3.96 (1.423)	4.40 (1.476)	3.66	3.96 (1.462)
4	759	4.14 (1.437)	3.99 (1.448)	4.13 (1.517)	3.69 (1.402)	3.84 (1.466)	4.32 (1.447)	3.93 (1.433)	4.25 (1.474)	3.50	3.77 (1.457)
5	762	4.37 (1.453)	3.99 (1.431)	4.26 (1.514)	3.89 (1.403)	4.10 (1.471)	4.47 (1.446)	3.96 (1.424)	4.44 (1.476)	3.81	4.11 (1.461)
6	772	4.34 (1.461)	3.96 (1.436)	4.31 (1.527)	3.77 (1.398)	3.95 (1.470)	4.31 (1.448)	3.90 (1.423)	4.44 (1.474)	3.68	3.99 (1.463)
7	776	4.16 (1.427)	4.05 (1.437)	4.14 (1.517)	3.87 (1.404)	4.11 (1.470)	4.35 (1.438)	3.99 (1.423)	4.40 (1.475)	3.71	4.04 (1.456)
8	790	4.35 (1.464)	3.99 (1.437)	4.31 (1.516)	3.77 (1.398)	3.99 (1.471)	4.32 (1.448)	3.96 (1.423)	4.41 (1.480)	3.72	4.01 (1.464)
9	808	4.17 (1.436)	4.04 (1.446)	4.11 (1.531)	3.77 (1.405)	3.92 (1.470)	4.31 (1.447)	3.98 (1.427)	4.34 (1.470)	3.56	3.81 (1.459)
10	816	4.32 (1.452)	3.92 (1.429)	4.23 (1.532)	3.84 (1.401)	4.07 (1.474)	4.31 (1.444)	3.90 (1.422)	4.41 (1.478)	3.60	4.08 (1.461)
11	817	4.17 (1.426)	4.07 (1.442)	4.23 (1.526)	3.84 (1.407)	4.04 (1.468)	4.35 (1.440)	3.98 (1.422)	4.41 (1.473)	3.63	3.93 (1.456)
12	902	4.32 (1.458)	3.98 (1.437)	4.28 (1.527)	3.84 (1.403)	3.99 (1.470)	4.32 (1.445)	3.96 (1.424)	4.41 (1.475)	3.84	4.08 (1.460)
13	923	4.29 (1.443)	3.92 (1.430)	4.22 (1.514)	3.83 (1.398)	3.99 (1.465)	4.32 (1.443)	3.93 (1.425)	4.41 (1.465)	3.72	4.01 (1.454)
14	925	4.28 (1.457)	3.98 (1.440)	4.19 (1.523)	3.83 (1.400)	3.99 (1.472)	4.32 (1.453)	3.98 (1.431)	4.38 (1.476)	3.65	4.08 (1.462)
15	927	4.32 (1.456)	3.96 (1.433)	4.28 (1.534)	3.87 (1.403)	4.04 (1.475)	4.35 (1.451)	3.96 (1.426)	4.41 (1.474)	3.62	4.04 (1.460)
16	941	4.29 (1.448)	3.95 (1.432)	4.31 (1.504)	3.84 (1.392)	4.01 (1.467)	4.32 (1.447)	3.99 (1.431)	4.44 (1.475)	3.63	4.08 (1.459)
17	944	4.17 (1.434)	4.05 (1.442)	4.16 (1.502)	3.83 (1.402)	3.89 (1.467)	4.31 (1.451)	4.01 (1.430)	4.34 (1.469)	3.50	3.93 (1.457)
18	977	4.32 (1.454)	3.92 (1.431)	4.31 (1.536)	3.72 (1.399)	4.01 (1.472)	4.28 (1.443)	3.87 (1.423)	4.44 (1.479)	3.66	4.01 (1.461)
19	979	4.29 (1.440)	3.89 (1.429)	4.37 (1.516)	3.80 (1.393)	3.96 (1.467)	4.25 (1.439)	3.87 (1.423)	4.49 (1.477)	3.60	4.05 (1.460)
20	981	4.26 (1.449)	3.89 (1.427)	4.28 (1.517)	3.80 (1.398)	3.95 (1.468)	4.32 (1.448)	3.92 (1.422)	4.44 (1.474)	3.35	4.05 (1.459)
	22°C	→	→	20°C	10°C →	→	24°C →	→	20°C	10°C →	→

Cell Capacities Shown in Ampere Hours
Peak Voltages Shown In Parenthesis

ORIGINAL PAGE IS OF POOR QUALITY

ORBITAL LOAD SH NG AND MATRIX TESTS

EFFICIENCY	N/A	92%	N/A	82%	N/A	90%	N/A	80%	N/A
CONDITION NO.	N/A	2	N/A	2	N/A	3	N/A	3	N/A
TEST NO.	25	28	30	33	35	38	40	43	45

CELL POSITION	CELL S/N	CALIBRATION CAPACITY CYCLE (01/20/77)	CAPACITY AFTER CYCLING (01/26/77)	CALIBRATION CAPACITY CYCLE (01/27/77)	CAPACITY AFTER CYCLING (02/02/77)	CALIBRATION CAPACITY CYCLE (02/03/77)	CAPACITY AFTER CYCLING (02/09/77)	CALIBRATION CAPACITY CYCLE (02/10/77)	CAPACITY AFTER CYCLING (02/16/77)	CALIBRATION CAPACITY CYCLE (02/17/77)
A1	745	4.37 (1.441)	4.10 (1.349)	4.19 (1.439)	4.19** (1.354)	4.08** (1.446)	-	-	-	-
A2	750	4.43 (1.434)	4.08 (1.344)	4.16 (1.544)	-	-	-	-	4.26** (1.353	4.18** (1.431)
A3	755	4.41 (1.439)	4.10 (1.347)	4.19 (1.438)	-	-	-	-	-	-
A4	759	4.22 (1.434)	3.98 (1.349)	4.05 (1.434)	-	-	-	-	-	-
A5	776	4.43 (1.437)	4.05 (1.350)	4.19 (1.432)	-	-	-	-	-	-
A6	808	4.29 (1.433)	3.98 (1.347)	4.08 (1.434)	-	-	-	-	-	-
A7	817	4.40 (1.437)	4.05 (1.350)	4.20 (1.434)	-	-	-	-	-	-
A8	902	4.43 (1.439)	4.10 (1.352)	4.23 (1.434)	-	-	4.20** (1.345)	4.11** (1.436)	-	-
A9	923	4.40 (1.431)	4.02 (1.344)	4.13 (1.430)	-	-	-	-	-	-
A10	941	4.46 (1.436)	4.10 (1.344)	4.20 (1.436)	-	-	-	-	-	-
A11	944	4.35 (1.436)	4.01 (1.344)	4.13 (1.440)	-	-	-	-	-	-
A12	979	4.49 (1.437)	4.11 (1.343)	4.20 (1.434)	-	-	-	-	-	-
B1	403	3.40* (1.425)	-	3.74 (1.373)	3.71 (1.359)	3.53 (1.437)	3.29 (1.345)	3.28 (1.434)	3.23 (1.337)	3.23 (1.434)
B2	511	3.62* (1.426)	-	4.20 (1.523)	3.83 (1.360)	3.72 (1.441)	3.42 (1.346)	3.45 (1.437)	3.39 (1.359)	3.47 (1.440)
B3	596	3.25* (1.414)	-	3.87 (1.365)	3.83 (1.360)	3.60 (1.432)	3.24 (1344)	3.23 (1.430)	3.18 (1.357)	3.20 (1.430)
B4	762	4.44 (1.441)	4.13 (1.349)	4.23 (1.437)	4.16 (1.357)	4.19 (1.437)	4.02 (1.344)	4.10 (1.439)	4.04 (1.359)	4.05 (1.438)
B5	772	4.44 (1.437)	4.08 (1.345)	4.19 (1.443)	4.16 (1.356)	4.16 (1.443)	4.02 (1.342)	4.05 (1.4 50)	4.01 (1.358)	4.01 (1.446)
B6	790	4.41 (1.442)	4.16 (1.351)	4.23 (1.442)	4.19 (1.356)	4.19 (1.443	4.10 (1.345)	4.11 (1.450)	4.10 (1.361)	4.08 (1.448)
B7	816	4.41 (1.441)	4.10 (1.350)	4.23 (1.434)	4.16 (1.353)	4.16 (1.437)	3.96 (1.343)	4.04 (1.439)	3.96 (1.358)	4.01 (1.435)
B8	925	4.38 (1.440)	4.10 (1.345)	4.20 (1.445)	4.19 (1.357)	4.20 (1.440)	4.02 (1.343)	4.05 (1.445)	4.04 (1.359)	4.04 (1.443)
B9	927	4.41 (1.436)	4.10 (1.345)	4.20 (1.441)	4.19 (1.356)	4.16 (1.437)	3.98 (1.342)	4.02 (1.440)	3.99 (1.357)	4.01 (1.437)
B10	977	4.44 (1.436)	4.05 (1.343)	4.20 (1.444)	4.19 (1.351)	4.11 (1.440)	3.92 (1.340)	3.99 (1.438)	3.95 (1.353)	3.93 (1.438)
B11	981	4.44 (1.437)	4.05 (1.346)	4.20 (1.438)	4.19 (1.355)	4.26 (1.438)	3.95 (1.342)	4.01 (1.436)	3.98 (1.356)	4.01 (1.435)
B12	**	**	**	**	**	**	**	**	**	**
	25°C →									

*Calibration Capacity Cycle on 01/24/77

**Capacities for orbital load sharing test of these cells performed on Matrix Load Sharing Tester

ORBITAL LOAD S[illegible]RING AND MATRIX TESTS

EFFICIENCY		90%	N/A	80%	N/A	99%	N/A	N/A	N/A	90%	N/A
CONDITION NO.		4	N/A	4	N/A	4	N/A	N/A	N/A	6	N/A
TEST NO.		48	50	53	55	58	60	63	66	68	70
CELL POSITION	CELL S/N	CAPACITY AFTER CYCLING (02/23/77)	CALIBRATION CAPACITY CYCLE (02/24/77)	CAPACITY AFTER CYCLING (03/02/77)	CALIBRATION CAPACITY CYCLE (03/03/77)	CAPACITY AFTER CYCLING (03/09/77)	CALIBRATION CAPACITY CYCLE (03/10/77)	CAPACITY AFTER CYCLING (03/16/77)	CALIBRATION CAPACITY CYCLE (03/17/77)	CAPACITY AFTER CYCLING (03/23/77)	CALIBRATION CAPACITY CYCLE (03/25/77)
A1	745	-	-	-	-	-	-	-	-	-	-
A2	750	-	-	-	-	-	-	-	-	-	-
A3	755	-	-	4.35*(1.349)	4.05*(1.421)	-	-	-	-	-	-
A4	759	-	-	-	-	-	-	4.23*(1.351)	3.77*(1.428)	-	-
A5	776	-	-	-	-	-	-	-	-	-	-
A6	808	-	-	-	-	-	-	-	-	-	-
A7	817	-	-	-	-	-	-	-	-	-	-
A8	902	-	-	-	-	-	-	-	-	-	-
A9	923	4.22*(1.345)	3.92*(1.418)	-	-	-	-	-	-	-	-
A10	941	-	-	-	-	4.37*(1.342)	4.08*(1.424)	-	-	-	-
A11	944	-	-	-	-	-	-	-	-	4.34*(1.347)	3.27*(1.393)
A12	979	-	-	-	-	-	-	-	-	-	-
B1	403	2.97 (1.347)	3.06 (1.419)	3.05 (1.352)	2.98 (1.413)	2.12 (1.319)	2.91 (1.420)	2.06 (1.286)	2.78 (1.424)	2.60 (1.377)	3.18 (1.560)
B2	511	3.26 (1.350)	3.32 (1.424)	3.29 (1.360)	3.23 (1.414)	2.34 (1.319	3.21 (1.426)	2.31 (1.292)	3.05 (1.426)	2.88 (1.377)	3.33 (1.550)
B3	596	3.00 (1.350)	3.03 (1.419)	3.08 (1.362)	2.96 (1.413)	2.06 (1.313)	2.93 (1.420)	1.94 (1.290)	2.75 (1.422)	2.57 (1.374)	3.48 (1.544)
B4	762	3.92 (1.351)	3.95 (1.426)	3.90 (1.359)	3.86 (1.418)	2.96 (1.316)	3.83 (1.435)	2.85 (1.295)	3.62 (1.434)	3.00 (1.371)	3.84 (1.464)
B5	772	3.98 (1.352)	3.95 (1.431)	3.98 (1.360)	3.86 (1.424)	3.09 (1.318)	3.87 (1.430)	3.00 (1.295)	3.68 (1.440)	3.17 (1.369)	3.77 (1.484)
B6	790	4.04 (1.351)	4.02 (1.433)	4.04 (1.361)	3.95 (1.425)	3.20 (1.319)	3.96 (1.432)	3.00 (1.293)	3.75 (1.442)	3.24 (1.377)	3.77 (1.476)
B7	816	3.83 (1.348)	3.81 (1.424)	3.83 (1.358)	3.74 (1.429)	2.81 (1.320)	3.71 (1.425)	2.73 (1.294)	3.48 (1.438)	3.12 (1.377)	3.78 (1.465)
B8	925	3.93 (1.345)	3.92 (1.428)	3.92 (1.359)	3.80 (1.422)	2.91 (1.315)	3.78 (1.426)	2.85 (1.294)	3.57 (1.437)	3.12 (1.375)	3.71 (1.471)
B9	927	3.84 (1.343)	3.87 (1.425)	3.87 (1.353)	3.74 (1.418)	2.82 (1.314)	3.72 (1.423)	2.78 (1.294)	3.50 (1.437)	3.09 (1.377)	3.78 (1.468)
B10	977	3.80 (1.349)	3.81 (1.424)	3.78 (1.354)	3.66 (1.417)	2.76 (1.316)	3.65 (1.423)	2.69 (1.294)	3.41 (1.436)	3.05 (1.375)	3.80 (1.485)
B11	981	3.84 (1.349)	3.86 (1.422)	3.83 (1.358)	3.72 (1.416)	2.81 (1.317)	3.69 (1.420)	2.73 (1.295)	3.47 (1.433)	3.08 (1.376)	3.72 (1.470)
B12	*	*	*	*	*	*	*	*	*	*	*
	26°C									10°C	

*Capacities for orbital load sharing test of these cells performed on Matrix Load Sharing Tester

ORIGINAL PAGE IS OF POOR QUALITY

ORBITAL LOAD SHAR[illegible] AND MATRIX TESTS

EFFICIENCY		80%	N/A	60%	N/A	90%	N/A	60%	N/A	93%	N/A	N/A
CONDITION NO.		6	N/A	6	N/A	5	N/A	5	N/A	1	N/A	N/A
TEST NO.		73	75	78	8[illegible]	83	85	88	90	93	95	97
CELL POSITION	CELL S/N	CAPACITY AFTER CYCLING (04/01/77)	CALIBRATION CAPACITY CYCLE (04/03/77)	CAPACITY AFTER CYCLING (04/11/77)	CALIBRATION CAPACITY CYCLE (04/13/77)	CAPACITY AFTER CYCLING (04/19/77)	CALIBRATION CAPACITY CYCLE (04/20/77)	CAPACITY AFTER CYCLING (04/26/77)	CALIBRATION CAPACITY CYCLE (04/27/77)	CAPACITY AFTER CYCLING (05/05/77)	CALIBRATION CAPACITY CYCLE (05/06/77)	CALIBRATION CAPACITY CYCLE (05/10/77)
A1	745	-	-	-	-	-	-	-	-	4.45(1.350)	3.98(1.412)	4.20(1.495)
A2	750	-	-	-	-	-	-	-	-	4.28(1.345)	3.83(1.412)	4.20(1.517)
A3	755	-	-	-	-	-	-	-	-	4.00(1.344)	3.84(1.416)	4.19(1.530)
A4	759	-	-	-	-	-	-	-	-	3.91(1.347)	3.75(1.415)	4.05(1.509)
A5	776	4.38*(1.348)	3.14*(1.389)	-	-	-	-	-	-	3.05(1.346)	3.45(1.411)	4.22(1.502)
A6	808	-	-	-	-	4.43*(1.343)	3.96*(1.418)	-	-	3.92(1.345)	3.81(1.414)	4.14(1.508)
A7	817	-	-	-	-	-	-	4.46*(1.344)	4.07*(1.422)	3.80(1.345)	3.84(1.412)	[illegible].17(1.504)
A8	902	-	-	-	-	-	-	-	-	4.31(1.347)	3.84(1.413)	4.20(1.509)
A9	923	-	-	-	-	-	-	-	-	3.87(1.344)	3.68(1.411)	4.19(1.505)
A10	941	-	-	-	-	-	-	-	-	4.13(1.347)	3.86(1.417)	4.25(1.522)
A11	944	-	-	-	-	-	-	-	-	3.00(1.343)	3.53(1.416)	4.13(1.510)
A12	979	-	-	4.02*(1.351)	3.11*(1.391)	-	-	-	-	3.48(1.346)	3.66(1.414)	4.22(1.540)
B1	403	2.85(1.373)	2.82(1.559)	2.97(1.369)	2.79(1.545)	3.32 1.338	3.12 1.555	3.02(1.328)	[illegible].14(1.555)	3.14(1.327)	3.32(1.419)	3.68(1.570)**
B2	511	3.02(1.401)	2.78(1.546)	2.79(1.390)	2.64(1.495)	3.15 1.336	3.03 1.537	3.14(1.332)	3.12(1.546)	2.93(1.302)	3.23(1.409)	3.75(1.570)**
B3	596	3.44(1.470)	3.39(1.568)	3.33(1.474)	3.33(1.566)	3.63 1.376	3.56 1.565	3.65(1.376)	3.69(1.565)	3.66(1.341)	3.51(1.416)	4.08(1.570)**
B4	762	3.59(1.411)	3.68(1.465)	3.71(1.434)	3.75(1.467)	4.20 1.365	4.20 1.478	4.22(1.369)	4.22(1.472)	4.29(1.336)	4.23(1.428)	4.25(1.500)
B5	772	3.56(1.[illegible]13)	3.72(1.491)	3.75(1.441)	3.83(1.490)	4.16 1.365	4.11 1.495	4.11(1.368)	4.16(1.490)	4.25(1.338)	4.19(1.428)	4.22(1.484)
B6	790	3.56(1.416)	3.68(1.482)	3.71(1.432)	3.78(1.485)	4.17 1.367	4.19 1.491	4.17(1.370)	4.22(1.485)	4.28(1.340)	4.23(1.426)	4.26(1.484)
B7	816	3.51(1.413)	3.57(1.464)	3.62(1.432)	3.65(1.469)	4.08 1.363	4.05 1.475	4.02(1.366)	3.99(1.471)	4.13(1.336)	4.14(1.434)	4.14(1.495)
B8	925	3.50(1.414)	3.62(1.476)	3.65(1.438)	3.72(1.477)	4.11 1.364	4.07 1.479	4.07(1.367)	4.07(1.477)	4.16(1.339)	4.14(1.433)	4.16(1.479)
B9	927	3.57(1.411)	3.65(1.472)	3.69(1.436)	3.72(1.472)	4.07 1.363	4.02 1.474	4.05(1.364)	4.02(1.471)	4.08(1.338)	4.04(1.426)	4.11(1.478)
B10	977	3.59(1.414)	3.71(1.491)	3.71(1.439)	3.75(1.487)	4.10 1.357	4.0[illegible] 1.482	4.02(1.363)	3.99(1.482)	4.05(1.340)	4.02(1.435)	4.13(1.481)
B11	981	3.53(1.411)	3.62(1.475)	3.65(1.436)	3.69(1.476)	4.13 1.359	4.14 1.477	4.13(1.367)	4.13(1.475)	4.25(1.339)	4.22(1.431)	4.22(1.493)
B12	*	*	*	*	*	*	*	*	*			
		10°C →				20°C →				27°C →		20°C

* Capacities for orbital load sharing test of these cells performed on matrix load sharing tester.
** Cell overvoltage detector removed cells from charge at 1.570 volts prior to completion of 20 hour charge period.

O-8